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(54) DEVICE FOR SCREENING CONVERGENCE INSUFFICIENCY AND RELATED COMPUTER IMPLEMENTED METHODS

VORRICHTUNG ZUM SCREENING VON KONVERGENZINSUFFIZIENZ UND ZUGEHÖRIGE COMPUTERIMPLEMENTIERTE VERFAHREN

DISPOSITIF POUR LE CRIBLAGE D'UNE INSUFFISANCE DE CONVERGENCE ET PROCÉDÉS MIS EN UVRE PAR ORDINATEUR APPARENTÉS

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Description

Technical Field

[0001] This present application relates to a medical device, and more particularly, to a device for screening visual issues in a patient.

Background

[0002] Convergence Insufficiency (CI) occurs when a subject's brain fails to coordinate images from both eyes while trying to focus on a nearby object. When a subject reads or looks at a close object, the subject's eyes must both turn inwardly (convergence) to focus. In studies that used standardized definitions of Convergence Insufficiency, investigators have reported a prevalence of 4.2% to 6% in school and clinic settings. Convergence Insufficiency is a common binocular vision disorder that is often associated with a variety of symptoms, including eyestrain, headaches, blurred vision, diplopia (double vision), sleepiness, difficulty concentrating, movement of print while reading, and loss of comprehension after short periods of reading or performing close activities.

[0003] Also, CI can cause difficulty with reading. This may make parents or teachers suspect that a child has a learning disability, instead of an eye disorder. In the past, CI disorder has often gone undetected because CI testing is not included in (1) a pediatrician's eye test; (2) school screenings; or (3) basic eye exams. A person can pass the 20/20 eye chart test and still have CI.

[0004] Currently, there is no consensus on norms for existing clinical methods for detecting CI or whether these are the only clinical measures required. Multiple subjective and objective decisions, including estimates of distance and time, are required by both the subject and the clinician. Objective measurements rely on examiner expertise and may be difficult for beginners to observe. Subjective measurements require patient cooperation to attain reliable results. In summary, present clinical methods have significant problems regarding accuracy and reproducibility, because they require subjective feedback from the subject, and because of clinician variability. Prior art documents US2015/0320306, EP2891953, WO2008/120635 and JP2002017677 disclose devices for measuring convergence.

Summary

[0005] Generally, a device is for screening a person for CI. The device may include a binocular viewer comprising a first eyepiece to receive a first eye of the person, a second eyepiece to receive a second eye of the person, a first image sensor adjacent the first eyepiece, and a second image sensor adjacent the second eyepiece, a display adjacent the binocular viewer, and a processor and associated memory cooperating with the display. The processor may be configured to record, with the first image sensor, movement of the first eye, record, with the second image sensor, movement of the second eye, and display on the display a first visual stimulus and a second visual stimulus. The processor may be configured to cause, in alternating fashion, convergent movement and divergent movement in the first visual stimulus and the second visual stimulus along a visual stimulus path, determine respective centroid positions of the second eye and the first eye during the convergent and divergent movement of the first visual stimulus and the second visual stimulus, and calculate an interpupillary distance (IPD), and compare the IPD with the visual stimulus path to obtain a dynamic IPD, the dynamic IPD serving as an indicator for whether the person has CI.

[0006] In some embodiments, a duration of each of the convergent movement and the divergent movement is 80-100 seconds. The device may also include a first infrared (IR) source configured to irradiate the first eye and a second IR illuminator configured to irradiate second eye, and the processor and memory may be configured to generate a first plurality of video frames showing movement of the first eye, and generate a second plurality of video frames showing movement of the second eye.

[0007] More specifically, the processor and memory may be configured to identify second blink pixels comprising second eye blinks in the second plurality of video frames, and form a third plurality of video frames by removing the second blink pixels from the second plurality of video frames. The processor and memory may be configured to identify first blink pixels comprising first eye blinks in the first plurality of video frames, and form a fourth plurality of video frames by removing the first blink pixels from the first plurality of video frames.

[0008] Also, the processor and memory may be configured to generate the first plurality of video frames by performing at least filtering each of the first plurality of video frames using a pixel intensity threshold to form a third plurality of video frames, each of the third plurality of video frames comprising a black background in combination with a white background, a first eye image, the third plurality of video frames comprising an N number of video frames, and filtering each of the second plurality of video frames using the pixel intensity threshold to form a fourth plurality of video frames, each of the fourth plurality of video frames comprising a black background in combination with a white background, a second eye image, the fourth plurality of video frames comprising an M number of video frames. The processor and memory may be configured to generate the first plurality of video frames by performing at least determining, for each of the third plurality of video frames, x and y coordinates for a first eye pupil centroid, and generating a first plurality of x coordinate datasets. An ith x coordinate dataset represents a location of an ith second pupil centroid, and i is greater than or equal to 1 and less than or equal to N. The processor and memory may be configured to generate the first plurality of video frames by performing at least determining, for each of the fourth plurality of video frames, x and y coordinates for a second eye pupil centroid, and generating a second plurality of x coordinate datasets. A jth x coordinate dataset represents a location of a jth first pupilar centroid, and j is greater than or equal to 1 and less than or equal to M.

[0009] The processor and memory may be configured to graphically display a first curve comprising N x coordinate datasets versus time, and graphically display a second curve comprising M x coordinate datasets versus time. The processor and memory may also be configured to set i=1 and j=1, subtract the ith x coordinate dataset from the jth x coordinate dataset to form a kth x coordinate dataset, each of the kth x coordinate dataset representing a hth dynamic IPD, when i is less than N, set i = i+1, when j is less than M, set j =j+1, and repeat the setting and the subtracting until at least one of i = N and j = M is true.

[0010] The processor and memory may be configured to form a third curve comprising each of the hth dynamic IPD versus time. The processor and memory may be configured to identify a first substantially linear portion of the third curve, the first substantially linear portion comprising a positive slope, identify a second substantially linear portion of the third curve, the second substantially linear portion comprising a negative slope, generate a graphical plot of the visual stimulus path, the graphical plot comprising a first linear portion comprising a positive slope and a second linear portion comprising a negative slope, overlap the third curve onto the graphical plot of the visual stimulus path, and adjust the third curve to fit onto graphical plot of the visual stimulus path. The processor and memory may be configured to compare the dynamic IPD with the visual stimulus path by performing at least optimizing a graph of dynamic IPDs with at least one parameter, and merging the optimized graph of dynamic IPDs with the visual stimulus path.

[0011] Another aspect is directed to a method for screening a person for CI. The method may include recording, with a first image sensor, movement of a first eye of the person, recording, with a second image sensor, movement of a second eye of the person, and displaying on a display a first visual stimulus and a second visual stimulus. The method may include causing, in alternating fashion, convergent movement and divergent movement in the first visual stimulus and the second visual stimulus along a visual stimulus path, determining respective centroid positions of the second eye and the first eye during the convergent and divergent movement of the first visual stimulus and the second visual stimulus, and using a processor and memory associated with the display, and the first and second image sensors for calculating an interpupillary distance (IPD), and comparing the IPD with the visual stimulus path to obtain a dynamic IPD, the dynamic IPD serving as an indicator for whether the person has CI.

[0012] Another aspect is directed to a device for screening a person for CI with a binocular viewer comprising a first eyepiece to receive a first eye of the person, a second eyepiece to receive a second eye of the person, a first image sensor adjacent the first eyepiece, and a second image sensor adjacent the second eyepiece. The device may include a display adjacent the binocular viewer, and a processor and associated memory cooperating with the display. The processor may be configured to record, with the first image sensor, movement of the first eye, record, with the second image sensor, movement of the second eye, and display on the display a first visual stimulus and a second visual stimulus. The processor may be configured to cause, in alternating fashion, convergent movement and divergent movement in the first visual stimulus and the second visual stimulus along a visual stimulus path, determine respective centroid positions of the second eye and the first eye during the convergent and divergent movement of the first visual stimulus and the second visual stimulus, and calculate an interpupillary distance (IPD), and compare the IPD with the visual stimulus path to obtain a dynamic IPD, the dynamic IPD serving as an indicator for whether the person has CI.

[0013] Another aspect is directed to a non-transitory computer-readable medium having computer-executable instructions for causing a computing device comprising a processor and associated memory to perform a method for screening a person for CI. The method may include recording, with a first image sensor, movement of a first eye of the person, recording, with a second image sensor, movement of a second eye of the person, and displaying on a display a first visual stimulus and a second visual stimulus. The method may include causing, in alternating fashion, convergent movement and divergent movement in the first visual stimulus and the second visual stimulus along a visual stimulus path, determining respective centroid positions of the second eye and the first eye during the convergent and divergent movement of the first visual stimulus and the second visual stimulus, and calculating an IPD, and comparing the IPD with the visual stimulus path to obtain a dynamic IPD, the dynamic IPD serving as an indicator for whether the person has CI.

Brief Description of the Drawings

[0014]

FIG. 1 is a schematic diagram of an apparatus to screen for CI, according to the present disclosure.

FIG. 2A is a schematic diagram of a binocular viewer **110** and a housing comprising one visual display, according to the present disclosure.

FIG. 2B is a schematic diagram of binocular viewer and the housing comprising one movable visual display, according to the present disclosure.

FIG. 3A is a schematic diagram of another embodiment of the binocular viewer and the housing comprising two visual displays, according to the present disclosure.

FIG. 3B is a schematic diagram of another embodiment of the binocular viewer and the housing comprising two movable visual displays, according to the present disclosure.

FIG. 4 is a flowchart showing a method to objectively screen for CI, according to the present disclosure.

FIG. 5 is a flowchart showing a method to process and analyze eye movement data recorded by cameras, according to the present disclosure.

FIG. 6A is a graph illustrating a programmed visual stimulus path, according to the present disclosure.

FIGS. 6B-6D are schematic diagrams showing the visual stimuli moving convergently and divergently, according to the present disclosure.

FIG. 7 are analog video frames of recorded eye movement at a certain time point, according to the present disclosure.

FIG. 8 are analog video frames of recorded eye movement during a blink, according to the present disclosure.

FIGS. 9A-9D are eye movement images, according to the present disclosure.

FIG. 10 is a graph of pupil positions in pixel numbers versus time and IPDs in pixel numbers versus time, according to the present disclosure.

FIG. 11 is a graph of IPDs in millimeters versus time, according to the present disclosure.

FIG. 12 is a graph of dynamic IPDs in millimeters versus times with an adjusted y-axis scale, according to the present disclosure.

FIGS. 13A-13C are graphs showing dynamic IPDs in degrees and prism diopters versus time, according to the present disclosure.

FIG. 14 is a graph of pupil positions in millimeters versus time of different sets of recorded eye movement during different cycles of visual stimuli convergence and divergence displaying, according to the present disclosure.

FIG. 15 is a schematic diagram of a controller depicted in FIG. 1.

FIGS. 16A and 16B are graphs of testing results in prism diopters, according to the present disclosure.

FIGS. 17-18 are images of example embodiments of the binocular viewer and associated equipment.

FIG. 19 is an image of an example embodiment for testing the device, according to the present disclosure.

Detailed Description

[0015] The present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which several embodiments of the invention are shown. This present disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present disclosure to those skilled in the art. Like numbers refer to like elements throughout.

[0016] Certain embodiments of Applicant's disclosure recite a method to screen a person for CI. The steps of the method comprise providing a screening apparatus, positioning a patient in front of the screening apparatus so that the patient looks into the apparatus, displaying visual stimuli convergently and divergently to generate a visual stimulus path, determining respective centroid positions of each eye, calculating an interpupillary distance (IPD) between the eyes, and comparing the IPD with the visual stimulus path to obtain a dynamic IPD, which is an indicator for whether the patient has CI.

[0017] Further, certain embodiments of Applicant's disclosure describe the screening apparatus with a binocular viewer and a housing attached to the binocular viewer. Further, the binocular viewer comprises two eyepieces, two mirrors, and two infrared (IR) illuminators; and the housing comprises two video cameras and a visual display device. In certain embodiments, the visual display is movable.

[0018] In certain embodiments, the binocular viewer comprises two eyepieces and two mirrors. The binocular viewer does not contain any (IR) illuminators. In other embodiments, the binocular viewer comprises two eyepieces, four mirrors, and two infrared (IR) illuminators. In yet some other embodiments, the binocular viewer comprises two eyepieces and four mirrors, without the IR illuminators. In addition, in certain embodiments, the visual display is movable.

[0019] The Applicant's disclosure is described in preferred embodiments in the following description with reference to the Figures, in which like numbers represent the same or similar elements. Reference throughout this specification to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment," "in an embodiment," and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment.

[0020] The described features, structures, or characteristics of the invention may be combined in any suitable manner in one or more embodiments. In the following description, numerous specific details are recited to provide a thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention may be practiced without one or more of the specific details, or with other methods, components, materials, and so forth. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

[0021] As a general matter when viewing an object, humans and many other animals enjoy stereoscopic vision. Because the two eyes are separated horizontally, the images perceived in the two eyes are slightly different and the difference is proportional to the relative depth.

The visual areas in the brain measure these differences, and "merge" the two different objects into a single object. In overview, Applicant's apparatus and method provide a mechanism to evaluate the ability of the subject's brain to merge the two perceived objects into a single 2-D or 3-D image.

[0022] Referring now to FIG. 1, Applicant's assembly for objectively screening subjects for Convergence Insufficiency comprises a binocular viewer **110**, a housing **120** attached to binocular viewer **110**, and a controller **130**. A subject 102 is positioned in front of binocular viewer **110**. Referring now to FIGS. 1, 2A and 2B, the subject **102** positions his or her eyes **202A** and **202B** in front of eyepieces **126** and **128**, respectively. In certain embodiments, the subject **102** places both hands on a surface supporting housing **120** to eliminate head movement during the examination. Further, the distance between the two eyepieces **126** and **128** can be adjusted to match a distance between the test subject's eyes **202A** and **202B**.

[0023] In other embodiments, a virtual reality (VR) mask / headset fits over binocular viewer **110**. Applicant has found that the VR mask faceplate can position the test subject's head into the best position for testing and reduce movement.

[0024] In certain embodiments, Applicant's apparatus comprises two (2) front surface mirrors and two (2) cold mirrors disposed in housing **120** and a single visual display device. In other embodiments, Applicant's apparatus comprises two (2) front surface mirrors and two (2) cold mirrors disposed in housing **120** and a single visual display device, wherein the visual display device is moveable within the housing.

[0025] In yet other embodiments, Applicant's apparatus comprises two (2) front surface mirrors and two (2) cold mirrors disposed in housing **120**, a single visual display device, and two (2) infrared emitters disposed in housing **120**. In still other embodiments, Applicant's apparatus comprises two (2) different front surface mirrors and two (2) cold mirrors disposed in housing **120**, a single visual display device, and two (2) infrared emitters disposed in housing **120**, wherein the visual display device is moveable within the housing.

[0026] In further embodiments, Applicant's apparatus comprises two (2) cold mirrors disposed in housing **120** and two different visual display devices. In other embodiments, Applicant's apparatus comprises two (2) front surface (or cold) different mirrors disposed in housing **120** and two different visual display devices, wherein one or more of the visual display devices is moveable within the housing. In further embodiments, Applicant's apparatus comprises two (2) different front surface (or cold) mirrors disposed in housing **120**, two (2) different visual display devices disposed in housing **120**, and two (2) infrared emitters disposed in housing **120**. In other embodiments, Applicant's apparatus comprises two (2) different front surface (or cold) mirrors disposed in housing **120**, two (2) different visual display devices disposed in housing **120**, and two (2) infrared emitters disposed in housing **120**, wherein one or more of the visual display devices is moveable within housing **120**.

[0027] Referring now to FIGS. 1 and 2A, housing **120** comprises a camera **240**, a camera **250**, and a visual display 230 (FIG. 2). A controller **130** is in communication with both cameras **240** and **250**, and the visual display **230**. Referring now to FIG. 15, controller **1500** comprises processor **1510**, memory **1520** interconnected with processor 1510 via communication link **1525**, optional Bluetooth module **1530** interconnected with processor **1510** via communication link **1535**, optional RFID module **1540** interconnected with processor **1510** via communication link **1545**, and optional "WI-FI" module **1550** interconnected with processor **1510** via communication link **1555**.

[0028] In the illustrated embodiment of FIG. 15, microcode **1522**, instructions **1524**, and database **1526**, are encoded in memory **1520**. In certain embodiments, memory **1520** comprises non-volatile memory. In certain embodiments, memory **1520** comprises battery backed up RAM, a magnetic hard disk assembly, an optical disk assembly, and/or electronic memory. By "electronic memory," Applicants mean a PROM, EPROM, EEPROM, SMARTMEDIA, FLASHMEDIA, and the like.

[0029] Processor **1510** uses microcode **1522** to operate controller **1500**. Processor **1510** uses microcode **1522**, instructions **1524**, and database **1526**, to operate Applicant's assembly **100,** Bluetooth module **1530**, RFID module **1540**, and WI-FI module **1550**.

[0030] In certain embodiments, processor **1510**, memory **1520**, optional Bluetooth module **1530**, optional RFID module **1540**, and optional "WI-FI" module **1550**, are integrated into an application specific integrated circuit, i.e. an "ASIC."

[0031] In the illustrated embodiment of FIG. 2A, the binocular viewer **110** comprises two eyepieces **126** and **128**, two infrared (IR) emitters **260** and **270**, and four mirrors **121**,**123**,**125**, and **127**. The eyepieces **126** and **128** are disposed in surface **110a** of binocular viewer **110**. Each eye sees a different, moveable stimulus on display **230**. In certain embodiments, the stimulus can be white shown on black background. In other embodiments, the stimulus can be black shown on white background.

[0032] In certain embodiments, mirrors **123** and **125** are cold mirrors, which allow light to go through on one side but is reflective on the other side, such as sides **123a** and **125a** are reflective (FIG. 2A, these sides facing subject's eyes); whereas mirrors **121** and **127** are surface mirrors, which reflect normally on one side and the other side is non-reflective to avoid extra light issue. For example, sides **121a** and **127a** (FIG. 2a) of the surface mirrors reflect normally. Further, the reflective side of a cold mirror can block about 90% of visible light, which has a spectrum up to about 650 nanometers. As described herein, "about" is used to describe a plus or minus 10% difference in any measurements. The non-reflective sides **123b** and **125b** (FIG. 2A) of mirrors **123** and **125** allow cameras **240** and **250** to be positioned behind mirrors without causing obstruction or distraction to testing subjects because they are looking at the reflective sides **123a** and **125a** of the mirrors during the test and cannot see the cameras. Further, in some embodiments, an IR filter **150** (FIG. 2B) is disposed parallel to mirror **125** and another IR filter **152** (FIG. 2B) is disposed parallel to mirror **123**. The IR filters block light of wavelengths up to about 700 nanometers and they assist in preventing the light from leaking back into the cameras **240** and **250**, which will cause blur or glare.

[0033] A first eye **202A** of a test subject 102 looks through the eyepiece **126** to observe moveable visual stimulus **236** shown on visual display **230**. A sight path for first eye **202A** passes through eyepiece **126** onto mirror **123**, is redirected by reflective surface **123a** onto mirror **121**, is redirected by reflective surface **121a** onto display **230**.

[0034] A second eye **202B** of a test subject 102 looks through the eyepiece **128** to observe moveable visual stimulus **234** shown on visual display **230**. A sight path for second eye **202A** passes through eyepiece **128** onto mirror **125**, is redirected by reflective surface **125a** onto mirror **127**, is redirected by reflective surface **127a** onto display **230**.

[0035] Mirror **121** and surface **110a** define a dihedral angle θ_a. Mirror 127 and surface 110a define a dihedral angle θ_b. In certain embodiments, angles θ_a and θ_b are about 135°. In a non-limiting embodiment, the dihedral angle between mirrors **123** and **125** is a right angle, i.e., the dihedral angle is about 90°.

[0036] Mirror **123** is substantially parallel to mirror **121**, with a reflective side **123a** having a facing relationship with the reflective side **121a** of mirror **121**. Mirror **125** is substantially parallel to mirror **127** with reflective side **125a** having a facing relationship with reflective side **127a** of mirror **127**.

[0037] Further, in the illustrated embodiment of FIG. 2A, infrared (IR) emitter **270** is disposed adjacent eyepiece **126**, and between mirrors **121** and **123**. Similarly, the infrared emitter **260** is disposed adjacent eyepiece **128**, and between the mirrors **125** and **127**. As those skilled in the art will appreciate, infrared radiation IR is invisible to human eyes, and comprises wavelengths longer than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nanometers (frequency 430 THz) to 1 mm (300 GHz). In a preferred embodiment, the IR emitters **260** and **270** operate at a wavelength of 940 nanometers, which eliminates any distraction to a testing subject.

[0038] Applicant has found that illuminating the eyes with infrared radiation eliminates unwanted artifacts in an eye image. The most distinctive feature in a recorded eye image is the contour of the pupil rather than limbus. Both the sclera and the iris strongly reflect infrared light, while only the sclera reflects visible light.

[0039] Applicant has further found that tracking the sharp contour of the pupil instead of the iris gives more reproducible results because the small size of the pupil makes it less likely to be occluded by an eyelid. Binocular viewer **110** and housing **120** are designed to block visible light. Therefore, infrared eye tracking can be employed without interference from visible light.

[0040] Referring to the illustrated embodiment of FIG. 2A again, housing **120** is attached to binocular viewer **110**, and comprises video camera **240** which is in communication with controller **130** via communication link **242**, video camera **250** which is in communication with controller **130** via communication link **252**, and visual display **230** which is in communication with controller **130** via communication link **232**. Video camera **240** transmits eye movement data in digital video frame to the controller **130** via communication link **242**. In certain embodiments, digital video frame data is transferred by video camera **240** to controller **130** in a digital bit stream. In certain embodiments, digital video frame data is transferred by video camera **240** to controller 130 as a digitized analog signal.

[0041] Video camera **250** transmits eye movement data in digital video frame to the controller **130** via communication link **252**. In certain embodiments, digital video frame data is transferred by video camera **250** to controller **130** in a digital bit stream. In certain embodiments, digital video frame data is transferred by video camera **250** to controller 130 as a digitized analog signal. In certain embodiments, the cameras **240** and **250** operate on fixed focus lenses, which are adjustable. In other embodiments, cameras **240** and **250** operate on auto focus lenses. In yet other embodiments, cameras **240** and **250** operate on telocentric lenses. In still other embodiments, cameras **240** and **250** operate on extended depth-of-field lenses.

[0042] In the illustrated embodiment of FIG. 2A, mirror **125** is disposed between video camera **240** and eyepiece **128**. Mirror **125** and IR filter **150** are used to block the infrared radiation from bouncing back and interfering with the cameras. Infrared emitter **260** shines infrared light onto eye **202B**, and video camera **240** is able to record the movement of eye **202B** because of that infrared illumination.

[0043] In the illustrated embodiment of FIG. 2A, mirror **123** is disposed between video camera **250** and eyepiece **128**. Mirror **123** and IR filter **152** are used to block the infrared radiation from bouncing back and interfering with the cameras. Infrared emitter **270** shines infrared light onto eye **202A**, and video camera **250** is able to record the movement of eye **202A** because of that infrared illumination.

[0044] Referring now to FIG. 6A, in certain embodiments controller **130** causes the displayed visual stimuli **234** and **236** to move convergently and divergently in an alternate manner using a preprogrammed visual stimulus path. In certain embodiments, visual stimuli **234** and **236** are initially substantially merged on the visual display device. Even though visual stimuli **234** and **236** are not actually merged on the display device, the subject perceives only a single image because the subject's brain has formed a single image from the two differing right eye image and left eye image. In other embodiments, visual stimuli **234** and **236** can start unconverged and move slowly into convergence.

[0045] The visual stimuli then move divergently, i.e. away from each other, in accord with curve **610** until a maximum separation is reached at point **630**. At some point along curve **610**, the subject's brain is unable to maintain a single image, and the subject perceives two different images.

[0046] Thereafter, visual stimuli **234** and **236** move convergently in accord with curve **620**. At some point along curve **620**, the subject's brain can once again form a single perceived image. In certain embodiments, the divergent movement of the visual stimuli, followed by convergent movement of those visual stimuli, takes about 90 seconds.

[0047] In certain embodiments, the beginning separation between visual stimuli **234** and **236** varies from about 120 to about 150 mm, and preferably at about 140 mm. In certain embodiments, the maximum separation between visual stimuli **234** and **236** at point **630** (FIG. 6A) varies from about 250 to about 310 mm, and preferably at about 300 mm.

[0048] In addition, the size of the stimuli **234** and **236** can be increased or decreased from one examination to another examination. Further, the brightness and the coloration of the stimuli **234** and **236** vary from one examination to another examination.

[0049] Referring to FIG. 6A, at point **601**, i.e. at the beginning of the procedure, the visual stimuli are separated by about 125 mm for about 5 seconds. Immediately thereafter at point **605**, the stimuli are instantly brought closer, i.e. to a separation of about 40 mm. At point **605**, the stimuli begin to separate, i.e. diverge, at a speed of about 1 to 3 mm/second, with the preferred speed of about 2 mm/second as shown by linear curve portion **610** having a positive slope.

[0050] When visual stimuli **234** and **236** reach a maximum separation at point **630**, which is about 230 mm on the visual display, the visual stimuli then converge, i.e. move towards each other (FIG. 6C). At point **657**, the visual stimuli are separated by about 40 mm. Immediately thereafter, the stimuli move apart to a separation of about 125 mm for about 20 seconds, and the procedure ends.

[0051] In certain embodiments, the divergence/convergence process repeats two or more times to generate multiple sets of video frames of eye movement to determine the reproducibility of Applicant's apparatus and method.

[0052] In certain embodiments, visual display device **230** can be moved backwardly / forwardly. In certain embodiments, one or more iterations of Applicant's method summarized hereinabove are performed with visual display device **230** at a first distance from eyepieces **126** and **128**. The visual display device is then repositioned at a second distance from eyepieces **126** and **128**, and Applicant's procedure is repeated. In certain embodiments, the second distance is less than the first distance. In other embodiments, the second distance is greater than the first distance.

[0053] Referring now to FIG. 2B, in certain embodiments visual display device **230** can be move forwardly and/or backwardly within housing **120**. Apparatus **205** comprises the elements of apparatus **200**, and further comprises locomotion assembly **280a** attached to a first end of visual display device **230**. Locomotion assembly **280a** is interconnected to controller **130** by communication link **284**. Locomotion tracks **295a** are positioned such that moveable wheels disposed on locomotion assembly **280a** can be disposed on locomotion tracks **295a**.

[0054] Apparatus **205** further comprises locomotion assembly **280b** attached to a second end of visual display device **230**. Locomotion assembly **280b** is interconnected to controller **130** by communication link **282**. Locomotion tracks **295b** are positioned such that moveable wheels disposed on locomotion assembly **280b** can be disposed on locomotion tracks **295b**.

[0055] As described hereinabove, in certain embodiments Applicant's apparatus comprises two mirror and two visual display devices. For example, in the illustrated embodiment of FIG. 3A, apparatus **300** comprises two mirrors and two visual display devices.

[0056] Apparatus **300** comprises a first mirror **323** comprising reflective surface **323a**. Mirror **323** is disposed between eyepiece **126** and video camera **250**. Sight path **305a** originates at eyepiece **126**, and includes reflective surface **323a**, and visual display device **324**. Display device **320** is interconnected to controller **130** via communication link **322**.

[0057] Apparatus 300 further comprises a second mirror **325** comprising reflective surface **325a**. Mirror **325** is disposed between eyepiece **128** and video camera **240**. Sight path **305b** originates at eyepiece **128**, and includes reflective surface **325a**, and visual display device **314**. Display device **310** is interconnected to controller **130** via communication link **312**.

[0058] Referring now to FIG. 3B, apparatus **305** includes the elements of apparatus **300** (FIG. 3A) and further includes a first locomotion assembly **280c** attached to a first end of visual display device **310**. Locomotion assembly **280c** is interconnected to controller **130** by communication link **315**. Locomotion tracks **318** are positioned such that moveable wheels disposed on locomotion assembly **280c** can be disposed on locomotion tracks **318**.

[0059] Apparatus **305** further comprises locomotion assembly **280d** attached to a second end of visual display device **310**. Locomotion assembly **280d** is interconnected to controller **130** by communication link **313**. Locomotion tracks **316** are positioned such that moveable wheels disposed on locomotion assembly **280d** can be disposed on locomotion tracks **316**.

[0060] Similarly, apparatus **305** comprises a third locomotion assembly **280e** attached to a first end of visual display device **320**, which is interconnected to controller

130 via communication link **322**. Locomotion assembly **280e** is interconnected to controller **130** by communication link **328**. Locomotion tracks **319** are positioned such that moveable wheels disposed on locomotion assembly **280e** can be disposed on locomotion tracks **319**. In addition, a fourth locomotion assembly **280f** attached to a second end of visual display device **320**. Locomotion assembly **280f** is interconnected to controller **130** by communication link. Locomotion tracks **317** are positioned such that moveable wheels disposed on locomotion assembly **280f** can be disposed on locomotion tracks **317**.

[0061] FIG. 4 summarizes the steps of Applicant's method using Applicant's apparatus. In step **410**, the method provides an apparatus configured to screen subjects for convergence insufficiency. In certain embodiments, the method in step **410** provides apparatus **200** (FIG. 2A). In certain embodiments, the method in step **410** provides apparatus **205** (FIG. 2B). In certain embodiments, the method in step **410** provides apparatus **300** (FIG. 3A). In certain embodiments, the method in step **410** provides apparatus **305** (FIG. 3B).

[0062] In step **420**, the method selects a form for a first visual stimulus. Further in step **420**, the method selects a form for a second visual stimulus. In certain embodiments, the form selected for the first visual stimulus is identical to the form selected for the second visual stimulus. For example, FIG. 6B shows a first visual stimulus and a second visual stimulus, wherein the first visual stimulus comprises the same form as the second visual stimulus. In other embodiments, the form selected for a first visual stimulus differs from the form selected for a second visual stimulus.

[0063] In step **430**, the method creates a stimulus path. For example, an illustrated stimulus path is depicted in FIG. 6A. Further, the size, the brightness, the beginning distance, and the moving speed of the two stimuli are determined in step **430**.

[0064] In step **440**, a testing subject 102 positions his or her eyes to look into eyepieces **126** and **128** disposed in binocular viewer **110**. In step **450**, the method initiates visual stimulus movement on one or more attached visual display devices. In addition, the method synchronously begins recording eye movement of both eyes.

[0065] In certain embodiments, a controller attached comprising a portion of the screening apparatus of step **410** performs step **430**. In certain embodiments, a controller attached to the screening apparatus wirelessly receives an instruction to perform step **430**.

[0066] In certain embodiments, recorded video frames of the eye movements of eye **202A** and eye **202B** are stored in a non-transitory computer readable medium **1520** (FIG. 15) by a processor **1510** (FIG. 15) disposed in controller **130**. In certain embodiments, computer readable medium **1520** comprises a magnetic storage medium, an optical storage medium, or an electronic storage medium. By electronic storage medium, Applicant means a PROM, EPROM, EEPROM, Flash PROM, compactflash, smartmedia, and the like.

[0067] In certain embodiments, the data calculation in steps **460**, **470**, and **480** can be performed after the examination. In other embodiments, the data calculation in steps **460**, **470**, and **480** can be performed in real time during the examination. In yet other embodiments, the data calculation in steps **460**, **470**, and **480** can be performed in slightly delayed real time during the examination. In step **460**, the method determines an interpupillary distance (IPD). IPD is the distance between the centers of the pupils of the two eyes. In certain embodiments, step **460** is performed by controller **1500** using processor **1510**, and microcode **1522**, and instructions **1524**. In certain embodiments, controller **1500** wirelessly receives an instruction to perform step **460**.

[0068] In step **470**, the method graphically curve fits a plot of IPD versus time. Now referring to FIG. 11, the method converts the IPDs in pixel numbers (FIG.10) to x coordinates in millimeters (mm). A curve **1110** is a display of IPDs in mm versus time in seconds. Further, a substantially linear portion **1120** of the curve **1110** comprising a positive slope and another substantially linear portion **1130** of the curve **1110** comprising a negative slope are identified. Additionally, random sample consensus (RANSAC), an iterative method to estimate parameters of a mathematical model from a set of observed data which contains errors and/or outliers, is used to remove errors and/or outliers and optimize the curve **1110**.

[0069] Further in step **470** and referring to FIG. 12, an optimal curve **1210** of dynamic IPDs is generated by further adjusting the scale of the y-axis in mm. The optimal curve **1210** is overlapped with the visual stimulus path **640**. Further, a substantially linear portion **1220** comprising a positive slope of the curve **1210** overlays with the positive slope **610** of the visual stimulus path **640** and another substantially linear portion **1230** comprising a negative slope of the curve **1210** overlays with the negative slope **620** of the visual stimulus path **640**. Moreover, point **1240**, which is the lowest value of a dynamic IPD on curve **1210**, is the point at which the stimuli appear to have merged for the testing subject and the point at which the testing subject's convergence should be at its maximum capacity. For example, when the substantially linear portion **1230** is long and the valley **1240** reaches down lower towards the x-axis, the testing subject is able to maintain convergence of the stimuli for a long time during the moving stimuli test, therefore, the testing subject is not convergence insufficient. Referring to FIG. 16B, a testing subject has a dynamic IPD of about -35 prism diopters and displays a good convergence. A range of -20 to -40 prism diopters in dynamic IPD is considered a range displaying good convergence. However, when the substantially linear portion **1230** is short and the valley **1240** does not reach down far towards the x-axis, the testing subject is not able to maintain convergence of the stimuli for a long time during the test, therefore, the testing subject may have CI. Referring to FIG. 16A, a different testing subject has a dynamic IPD of -15 prism diopters and displays a poor convergence.

[0070] Referring to FIGS. 13A-13C, the curve **1210** with dynamic IPDs in mm is transitioned to a curve **1310** with dynamic IPDs in degrees. Further, the curve **1310** with dynamic IPDs in degrees is transitioned to a curve **1320** with dynamic IPDs in prism diopters. An antapex **1330** indicates the testing subject's maximum amount of convergence in prism diopters to the stimuli and is used as the primary determinant for CI.

[0071] In certain embodiments, step **470** is performed by controller **1500** using processor **1510**, and microcode **1522**, and instructions **1524**. In certain embodiments, controller **1500** wirelessly receives an instruction to perform step **470**.

[0072] In step **480**, the method determines a dynamic IPD for the test subject. In certain embodiments, step **480** is performed by controller **1500** using processor **1510**, and microcode **1522**, and instructions **1524**. In certain embodiments, controller **1500** wirelessly receives an instruction to perform step **480**.

[0073] In certain embodiments, step **460** comprises the steps recited in FIG. 5.

[0074] Referring to the illustrated embodiment in FIG. 5, step **510**, video camera **250** records the movements of eye **202B** and generates a plurality of video frames during the visual stimuli path described in step **430** (FIG. 4) Video camera **240** records the movements of eye **202A** and generates a plurality of video frames during the visual stimuli path described in step **430** (FIG. 4). In certain embodiments, the frequency of the recorded video frames is about 0.1 sec per frame. A video frame at a certain time point is illustrated in FIG. 7. Referring now to FIG. 8, an eye blink is detected, and the video frame of the blink is further removed from the plurality of video frames generated in step **510** and step **515**. Some testing subjects blink more frequently and use blinking as a way to reset the convergence system in their eyes. Applicant's apparatus is able to record the frequency and specific times of occurred blinks, which are additional information that can be utilized to determine CI.

[0075] Referring to FIGS. 9A-9D, the illustrated embodiment of the eye images demonstrates a test analysis sequence. In step **530** and **535**, analog picture frames (FIG. 9A) are directly provided by camera **240** and **250**, respectively. In steps **530** and **535**, the method sets a pixel intensity threshold. A pixel intensity threshold is set by a computer readable program. In certain embodiments, the computer readable program is MATLAB. In certain embodiments, steps **530** and **535** are performed by controller **1500** using processor **1510**, and microcode **1522**, and instructions **1524**. In certain embodiments, controller **1500** wirelessly receives an instruction to perform steps **530** and **535**.

[0076] In steps **540** and **545**, the method applies the pixel intensity threshold of steps **530** and **535**, respectively, to each analog video frame to form a binary eye image illustrated in FIG. 9B comprising a black background and a white **202A** or **202B** eye image. Further, as illustrated in FIG. 9C, the borders of the binary eye image and small blobs (small white spots embedded in the black background) are cleared to form a uniform black background, as illustrated in FIG. 9D. Further, referring to FIG. 9D, the x-axis and the y-axis coordinates in pixel numbers of the white eye blob are determined by the computer readable program. This illustrated test analysis is repeated with every analog video frame until the last frame of either eye **202A** or **202B** to generate a plurality of N video frames of eye **202A** and a plurality of M video frames of eye **202B**.

[0077] In steps **550** and **555**, the method generates a plurality of x coordinate values of eye **202A** and **202B** respectively are determined. An (i)th x coordinate data represents the location of an (i)th pupil centroid of the eye **202A** and a (j)th x coordinate data represents the location of an (j)th pupil centroid of the eye **202B**. In certain embodiments, steps **550** and **555** are performed by controller **1500** using processor **1510**, and microcode **1522**, and instructions **1524**. In certain embodiments, controller **1500** wirelessly receives an instruction to perform step **550** and **555**.

[0078] Referring to FIG. 10, in steps of 570 and 575 the method graphically displays a first graph comprising left eye x coordinates versus time. The method further graphically displays a second graph comprising right eye x coordinates versus time. In certain embodiments, steps **570** and **575** are performed by controller **1500** using processor **1510**, and microcode **1522**, and instructions **1524**. In certain embodiments, controller **1500** wirelessly receives an instruction to perform steps **570** and **575**.

[0079] In step **570**, the method for each time value, subtracts a left eye x coordinate from a right eye x coordinate to form a IPD for that time value. In certain embodiments, step **570** is performed by controller **1500** using processor **1510**, and microcode **1522**, and instructions **1524**. In certain embodiments, controller **1500** wirelessly receives an instruction to perform step **570**.

[0080] FIG. 10 illustrates a first graph showing right eye determined centroids versus time. FIG. 10 illustrates a second graph showing left eye determined centroids versus time. FIG. 10 further illustrates a third graph which comprises for each time value, the difference between a left eye x coordinate for that time value from a right eye x coordinate for that time value.

[0081] In step **590** and referring to FIG. 10, the dynamic IPDs calculated in step **570** are graphically displayed versus time. In the illustrated embodiment of FIG. 14, three curves of dynamic IPDs versus time from different sets of video frames of eye movement recorded during different process of visual stimuli' divergence and convergence match each other substantially, which demonstrates a strong reproducibility of the Applicant's method in screening for Convergence Insufficiency.

[0082] While the preferred embodiments of the present invention have been illustrated in detail, it should be apparent that modifications and adaptations to those embodiments may occur to one skilled in the art without departing from the scope of the present invention.

[0083] Referring now to FIGS. 17-18, a desirable product requirement of a CI screener is the ability to make measurements on a subject with prescription eyeglasses or contact lenses. As shown in FIG. 2A, using one IR light emitting diode (LED) per eye, this method works well without glasses or with contact lenses, providing a distinctive glint reflection that is easy to detect using established machine vision methods. However, this does not work well while wearing prescription glasses because the prescription lenses also reflect the infrared light, creating an additional glint blocking and obscuring the camera view of the glint/pupil/eye.

[0084] A standard way to suppress the glasses' reflection is to use a diffuse lighting illumination configuration. This is typically done with a ring structure of LEDs. However, this may be expensive, requiring multiple LEDs in a complex mechanical ring mount. Even more importantly, it may raise eye safety concerns with so many LEDs in close proximity to the eye.

[0085] FIG. 17 shows a unique diffuse illumination method composed of a flexible side glow optical fiber that has a superb light transmission for bright and consistent illumination using one or two LEDs. When mounted in an eye mask in a ring or oval configuration as shown in FIG. 18, it creates a diffuse eye illumination method that suppresses glint reflections from the eyeglasses as well as the eye. Of course, these features could be added to any of the above embodiments.

Explicit Near Point Convergence Test Disclosure

[0086] Referring now to FIG. 19, the standard clinical methods to screen for CI include a near point convergence test. This test requires a subject to adjust his focus as well as his convergence while a visual stimulus is moved in toward his nose. In this way, the subject's ability to simultaneously accommodate and converge is dynamically tested.

[0087] FIG. 2B shows a mechanical configuration which allows the system to explicitly mimic the clinical near point test. Technically, it is a single visual stimulus display configuration with a variable image distance, all under computer control. FIG. 19 shows an example embodiment prototype.

[0088] Other features relating to screening devices are disclosed in co-pending application: titled "DEVICE FOR SCREENING CONVERGENCE INSUFFICIENCY AND RELATED METHODS," Attorney Docket No. 0127321.

[0089] Many modifications and other embodiments of the present disclosure will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the present disclosure is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

Claims

1. A device for screening a person for convergence insufficiency (CI) with a binocular viewer comprising a first eyepiece to receive a first eye of the person, a second eyepiece to receive a second eye of the person, a first image sensor adjacent the first eyepiece, and a second image sensor adjacent the second eyepiece, the device comprising:

    a display adjacent the binocular viewer; and
    a processor and associated memory cooperating with said display and configured to

        record, with the first image sensor, movement of the first eye,
        record, with the second image sensor, movement of the second eye,
        display on said display a first visual stimulus and a second visual stimulus,
        cause, in alternating fashion, convergent movement and divergent movement in the first visual stimulus and the second visual stimulus along a visual stimulus path,
        determine respective centroid positions of the second eye and the first eye during the convergent and divergent movement of the first visual stimulus and the second visual stimulus, and
        calculate an interpupillary distance (IPD), and compare the IPD with the visual stimulus path to obtain a dynamic IPD, the dynamic IPD serving as an indicator for whether the person has CI.

2. The device of claim 1 wherein a duration of each of the convergent movement and the divergent movement is 80-100 seconds.

3. The device of claim 1 or 2 further comprising a first infrared (IR) source configured to irradiate the first eye and a second IR illuminator configured to irradiate second eye; and wherein said processor and memory are configured to generate a first plurality of video frames showing movement of the first eye, and generate a second plurality of video frames showing movement of the second eye.

4. The device of claim 3 wherein said processor and memory are configured to:

    identify second blink pixels comprising second eye blinks in the second plurality of video frames;
    form a third plurality of video frames by removing the second blink pixels from the second plurality of video frames;
    identify first blink pixels comprising first eye

blinks in the first plurality of video frames; and
form a fourth plurality of video frames by removing the first blink pixels from the first plurality of video frames.

5. The device of claim 3 or 4 wherein said processor and memory are configured to generate the first plurality of video frames by performing at least:

filtering each of the first plurality of video frames using a pixel intensity threshold to form a third plurality of video frames, each of the third plurality of video frames comprising a black background in combination with a white background, a first eye image, the third plurality of video frames comprising an N number of video frames;
filtering each of the second plurality of video frames using the pixel intensity threshold to form a fourth plurality of video frames, each of the fourth plurality of video frames comprising a black background in combination with a white background, a second eye image, the fourth plurality of video frames comprising an M number of video frames;
determining, for each of the third plurality of video frames, x and y coordinates for a first eye pupil centroid; and
generating a first plurality of x coordinate datasets;
wherein an ith x coordinate dataset represents a location of an ith second pupil centroid;
wherein i is greater than or equal to 1 and less than or equal to N;
determining, for each of the fourth plurality of video frames, x and y coordinates for a second eye pupil centroid; and
generating a second plurality of x coordinate datasets;
wherein a jth x coordinate dataset represents a location of a jth first pupilar centroid;
wherein j is greater than or equal to 1 and less than or equal to M.

6. The device of claim 5 wherein said processor and memory are configured to:

graphically display a first curve comprising N x coordinate datasets versus time; and
graphically display a second curve comprising M x coordinate datasets versus time.

7. The device of claim 6 wherein said processor and memory are configured to:

set i=1 and j=1;
subtract the ith x coordinate dataset from the jth x coordinate dataset to form a kth x coordinate dataset, each of the kth x coordinate dataset represents a hth dynamic IPD;
when i is less than N, set i = i+1;
when j is less than M, set j = j+1; and
repeat the setting and the subtracting until at least one of i = N and j = M is true.

8. The device of claim 7 wherein said processor and memory are configured to form a third curve comprising each of the hth dynamic IPD versus time.

9. The device of claim 8 wherein said processor and memory are configured to:

identify a first substantially linear portion of the third curve, the first substantially linear portion comprising a positive slope;
identify a second substantially linear portion of the third curve, the second substantially linear portion comprising a negative slope;
generate a graphical plot of the visual stimulus path, the graphical plot comprising a first linear portion comprising a positive slope and a second linear portion comprising a negative slope;
overlap the third curve onto the graphical plot of the visual stimulus path; and
adjust the third curve to fit onto graphical plot of the visual stimulus path.

10. The device of any preceding claim wherein said processor and memory are configured to compare the dynamic IPD with the visual stimulus path by performing at least:

optimizing a graph of dynamic IPDs with at least one parameter; and
merging the optimized graph of dynamic IPDs with the visual stimulus path.

11. A non-transitory computer-readable medium having computer-executable instructions for causing a computing device comprising a processor and associated memory to perform a method for screening a person for convergence insufficiency (CI), the method comprising:

recording, with a first image sensor, movement of a first eye of the person;
recording, with a second image sensor, movement of a second eye of the person;
displaying on a display a first visual stimulus and a second visual stimulus;
causing, in alternating fashion, convergent movement and divergent movement in the first visual stimulus and the second visual stimulus along a visual stimulus path;
determining respective centroid positions of the second eye and the first eye during the convergent and divergent movement of the first visual

stimulus and the second visual stimulus; and calculating an interpupillary distance (IPD), and comparing the IPD with the visual stimulus path to obtain a dynamic IPD, the dynamic IPD serving as an indicator for whether the person has CI.

12. The non-transitory computer-readable medium of claim 11 wherein a duration of each of the convergent movement and the divergent movement is 80-100 seconds.

13. The non-transitory computer-readable medium of claim 11 or 12 wherein the method comprises:

using a first infrared (IR) source configured to irradiate the first eye and a second IR illuminator configured to irradiate second eye; and
generating a first plurality of video frames showing movement of the first eye, and generating a second plurality of video frames showing movement of the second eye.

14. The non-transitory computer-readable medium of claim 13 wherein the method comprises:

identifying second blink pixels comprising second eye blinks in the second plurality of video frames;
forming a third plurality of video frames by removing the second blink pixels from the second plurality of video frames;
identifying first blink pixels comprising first eye blinks in the first plurality of video frames; and
forming a fourth plurality of video frames by removing the first blink pixels from the first plurality of video frames.

15. The non-transitory computer-readable medium of claim 13 or 14 wherein the generating of the first plurality of video frames comprises:

filtering each of the first plurality of video frames using a pixel intensity threshold to form a third plurality of video frames, each of the third plurality of video frames comprising a black background in combination with a white background, a first eye image, the third plurality of video frames comprising an N number of video frames;
filtering each of the second plurality of video frames using the pixel intensity threshold to form a fourth plurality of video frames, each of the fourth plurality of video frames comprising a black background in combination with a white background, a second eye image, the fourth plurality of video frames comprising an M number of video frames;
determining, for each of the third plurality of video frames, x and y coordinates for a first eye pupil centroid; and
generating a first plurality of x coordinate datasets;
wherein an ith x coordinate dataset represents a location of an ith second pupil centroid;
wherein i is greater than or equal to 1 and less than or equal to N;
determining, for each of the fourth plurality of video frames, x and y coordinates for a second eye pupil centroid; and
generating a second plurality of x coordinate datasets;
wherein a jth x coordinate dataset represents a location of a jth first pupilar centroid;
wherein j is greater than or equal to 1 and less than or equal to M.

Patentansprüche

1. Einrichtung zum Screening von Konvergenzinsuffizienz (CI) mit einem Binokular umfassend ein erstes Okular, um ein erstes Auge der Person aufzunehmen, ein zweites Okular, um ein zweites Auge der Person aufzunehmen, einen ersten Bildsensor angrenzend an das erste Okular und einen zweiten Bildsensor angrenzend an das zweite Okular, wobei die Einrichtung umfasst:

eine Anzeige angrenzend an das Binokular; und einen Prozessor und einen zugeordneten Speicher, der mit der Anzeige kooperiert und ausgebildet ist, um

mit dem ersten Sensor die Bewegung des ersten Auges aufzuzeichnen,
mit dem zweiten Bildsensor die Bewegung des zweiten Auges aufzuzeichnen,
auf der Anzeige einen ersten visuellen Reiz und einen zweiten visuellen Reiz anzuzeigen,
auf wechselnde Art eine konvergierende Bewegung und divergierende Bewegung des ersten visuellen Reizes und des zweiten visuellen Reizes entlang einer visuellen Reizbahn zu erwirken,
entsprechende Schwerpunktlagen des zweiten Auges und des ersten Auges während der konvergenten und divergenten Bewegung des ersten visuellen Reizes und des zweiten visuellen Reizes zu ermitteln, und
einen Augenabstand (IPD) zu berechnen und um den IPD mit der visuellen Reizbahn zu vergleichen, um einen dynamischen IPD zu erhalten, wobei der dynamische IPD als eine Anzeige dazu dient, ob die Person CI hat.

2. Einrichtung nach Anspruch 1, bei der die Dauer von sowohl der konvergenten Bewegung als auch der divergenten Bewegung 80-100 Sekunden beträgt.

3. Einrichtung nach Anspruch 1 oder 2 ferner umfassend eine erste Infrarotquelle (IR), die ausgebildet ist, um das erste Auge zu bestrahlen und eine zweite Infrarotbeleuchtung (IR), die ausgebildet ist, um das zweite Auge zu bestrahlen, und wobei der Prozessor und der Speicher ausgebildet sind, um eine erste Vielzahl Videoframes zu erzeugen, die die Bewegung des ersten Auges zeigen, und um eine zweite Vielzahl Videoframes zu erzeugen, die die Bewegung des zweiten Auges zeigen.

4. Einrichtung nach Anspruch 3, bei der der Prozessor und der Speicher ausgebildet sind, um zweite Blinkpixel zu ermitteln umfassend zweite Augenblinkvorgänge in der zweiten Vielzahl Videoframes;
um aus einer dritten Vielzahl Videoframes durch Entfernen der zweiten Blinkpixel von der zweiten Vielzahl Videoframes erste Blinkpixel zu ermitteln, umfassend erste Augenblinkvorgänge in der ersten Vielzahl Videoframes; und
um eine vierte Vielzahl Videoframes auszubilden durch Entfernen der ersten Blinkpixel von der ersten Vielzahl Videoframes.

5. Einrichtung nach Anspruch 3 oder 4, bei der der Prozessor und Speicher ausgebildet sind, um die erste Vielzahl Videoframes zu erzeugen durch Durchführen von zumindest:

Filtern von jeder der ersten Vielzahl Videoframes umfassend einen Pixelintensitätsgrenzwert, um eine dritte Vielzahl Videoframes auszubilden, wobei jeder der dritten Vielzahl Videoframes einen schwarzen Hintergrund in Kombination mit einem weißen Hintergrund, ein erstes Augenbild, die dritte Vielzahl Videoframes umfassend eine N-Anzahl Videoframes umfasst;
Filtern von sowohl der zweiten Vielzahl Videoframes verwendend den Pixelintensitätsgrenzwert, um eine vierte Vielzahl Videoframes auszubilden, wobei jeder der vierten Vielzahl Videoframes einen schwarzen Hintergrund in Verbindung mit einem weißen Hintergrund, ein zweites Augenbild sowie die vierte Vielzahl Videoframes umfassend eine M-Anzahl Videoframes umfasst;
Ermitteln für jeden der dritten Vielzahl Videoframes x- und y-Koordinaten für den ersten Pupillenschwerpunkt; und
Erzeugen einer ersten Vielzahl x-Koordinatendatensätze;
wobei ein i-ter x-Koordinatendatensatz einen Ort eines i-ten zweiten Pupillenschwerpunkts wiedergibt;
wobei i größer als oder gleich 1 und geringer als oder gleich N ist;
Ermitteln für jeden der Vielzahl Videoframes x- und y-Koordinaten für einen zweiten Augenpupillenschwerpunkt; und
Erzeugen einer zweiten Vielzahl an x-Koordinatendatensätze;
wobei ein j-ter x-Koordinatendatensatz einen Ort eines j-ten- ersten Pupillenschwerpunkts wiedergibt;
wobei j größer als oder gleich 1 und geringer als oder gleich M ist.

6. Einrichtung nach Anspruch 5, bei der der Prozessor und Speicher ausgebildet sind, um graphisch eine erste Kurve umfassend N x-Koordinatendatensätze über der Zeit darzustellen; und um graphisch eine zweite Kurve darzustellen, umfassend M x-Koordinatendatensätze über der Zeit.

7. Einrichtung nach Anspruch 6, bei der der Prozessor und Speicher ausgebildet sind, um:

i=1 und j=1 zu setzen;
um den i-ten x-Koordinatendatensatz von dem j-ten x-Koordinatensatz zu subtrahieren, um einen k-ten x-Koordinatendatensatz auszubilden, wobei jeder k-te x-Koordinatendatensatz einen h-ten dynamischen IPD wiedergibt;
wobei, wenn i geringer als N ist, i=i+1 gesetzt wird;
wobei, wenn j geringer als M ist, j=j+1 gesetzt wird; und
wobei das Einstellen und Subtrahieren wiederholt wird bis zumindest i=1 und/oder j=M erfüllt ist.

8. Einrichtung nach Anspruch 7, bei der der Prozessor und Speicher ausgebildet sind, um eine dritte Kurve auszubilden, umfassend jeden der h-ten dynamischen IPD über der Zeit.

9. Einrichtung nach Anspruch 8, bei der der Prozessor und Speicher ausgebildet sind, um:

einen ersten im Wesentlichen linearen Abschnitt der dritten Kurve zu identifizieren, wobei der erste im Wesentlichen lineare Abschnitt eine positive Steigung umfasst;
einen zweiten im Wesentlichen linearen Abschnitt der dritten Kurve zu identifizieren, wobei der zweite im Wesentlichen lineare Abschnitt eine negative Steigung umfasst;
eine graphische Anzeige der visuellen Reizbahn zu erzeugen, wobei die graphische Anzeige einen ersten linearen Abschnitt umfassend eine positive Neigung und einen zweiten linearen Ab-

schnitt umfassend eine negative Neigung umfasst;
die dritte Kurve auf die graphische Anzeige der visuellen Reizbahn zu überlappen; und
die dritte Kurve einzustellen, um auf die graphische Anzeige der visuellen Reizbahn zu passen.

10. Einrichtung nach einem der vorhergehenden Ansprüche, bei der der Prozessor und Speicher ausgebildet sind, um die dynamische IPD mit der visuellen Reizbahn zu vergleichen, durch zumindest ausführen von:

Optimieren eines Graphs von dynamischen IPDs mit zumindest einem Parameter; und
Vereinen des optimierten Graphen der dynamischen IPDs mit der visuellen Reizbahn.

11. Nicht-flüchtiges, computerlesbares Medium aufweisend computerausführbare Anweisungen zum Erwirken, dass eine Computereinrichtung umfassend einen Prozessor und einen zugeordneten Speicher ein Verfahren zum Screening einer Person auf Konvergenzinsuffizienz (CI) durchführt, wobei das Verfahren umfasst:

Aufzeichnen mit einem ersten Bildsensor einer Bewegung eines ersten Auges der Person;
Aufzeichnen mit einem zweiten Bildsensor einer Bewegung eines zweiten Auges der Person;
Anzeigen auf einer Anzeige eines ersten visuellen Reizes und eines zweiten visuellen Reizes; und
Hervorrufen auf alternierende Weise einer konvergierenden Bewegung und einer divergierenden Bewegung in dem ersten visuellen Reiz und dem zweiten visuellen Reiz entlang einer visuellen Reizbahn;
Ermitteln von entsprechenden Schwerpunktpositionen des ersten Auges und des zweiten Auges während der konvergenten und divergenten Bewegung des ersten visuellen Stimulus und des zweiten visuellen Stimulus; und
Berechnen eines Augenabstandes (IPD) und Vergleichen des Augenabstandes mit der visuellen Reizbahn, um eine dynamische IPD zu erhalten, wobei die IPD als ein Indikator dafür dient, ob die Person CI hat.

12. Nicht-flüchtiges, computerlesbares Medium nach Anspruch 11, bei dem eine Dauer von sowohl der konvergenten Bewegung als auch der divergenten Bewegung 80-100 Sekunden beträgt.

13. Nicht-flüchtiges, computerlesbares Medium nach Anspruch 11 oder 12, bei dem das Verfahren aufweist:

Verwenden einer ersten Infrarotquelle (IR), die ausgebildet ist, um das erste Auge zu bestrahlen, und einer zweiten IR-Beleuchtung, die ausgebildet ist, um das zweite Auge zu bestrahlen; und
Erzeugen einer ersten Vielzahl Videoframes, die eine Bewegung des ersten Auges zeigt, und Erzeugen einer zweiten Vielzahl Videoframes, die eine Bewegung des zweiten Auges zeigt.

14. Nicht-flüchtiges, computerlesbares Medium nach Anspruch 13, bei dem das Verfahren umfasst:

Identifizieren zweiter Blinkpixel umfassend zweite Augenblinkvorgänge in der zweiten Vielzahl Videoframes;
Ausbilden einer dritten Vielzahl Videoframes durch Entfernen der zweiten Blinkpixel aus der zweiten Vielzahl Videoframes;
Identifizieren der ersten Blinkpixel umfassend erste Augenblinkvorgänge in der ersten Vielzahl Videoframes; und
Ausbilden einer vierten Vielzahl Videoframes durch Entfernen der ersten Blinkpixel aus der ersten Vielzahl Videoframes.

15. Nicht-flüchtiges computerlesbares Medium nach Anspruch 13 oder 14, bei dem das Erzeugen der ersten Vielzahl Videoframes umfasst:

Filtern von jedem der ersten Vielzahl Videoframes unter Verwendung eines Pixelintensitätsgrenzwertes, um eine dritte Vielzahl Videoframes auszubilden, wobei jeder der dritten Vielzahl Videoframes einen schwarzen Hintergrund in Verbindung mit einem weißen Hintergrund, ein erstes Augenbild, die dritte Vielzahl Videoframes umfassend eine N-Anzahl Videoframes umfasst;
Filtern von jeder der zweiten Vielzahl Videoframes unter Verwendung des Pixelintensitätsgrenzwertes, um eine vierte Vielzahl Videoframes auszubilden, wobei jeder der vierten Vielzahl Videoframes einen schwarzen Hintergrund in Verbindung mit einem weißen Hintergrund, ein zweites Augenbild, die vierte Vielzahl Videoframes umfassend eine M-Anzahl Videoframes umfasst;
Ermitteln für jeden der dritten Vielzahl Videoframes x- und y-Koordinaten für einen ersten Augenpupillenschwerpunkt; und
Erzeugen einer ersten Vielzahl x-Koordinatendatensätze;
wobei ein i-ter x-Koordinatendatensatz einen Ort eines i-ten zweiten Pupillenschwerpunktes wiedergibt;
wobei i größer als oder gleich 1 und geringer als oder gleich N ist;

Ermitteln für jeden der vierten Vielzahl Videoframes x- und y-Koordinaten für einen zweiten Augenpupillenschwerpunkt; und

Erzeugen einer zweiten Vielzahl x-Koordinatendatensätze;

wobei ein j-ter x-Koordinatendatensatz einen Ort eines j-ten ersten Pupillenschwerpunkts wiedergibt;

wobei j größer als oder gleich 1 und geringer als oder gleich M ist.

Revendications

1. Dispositif de dépistage d'une insuffisance de convergence (CI) d'une personne avec une visionneuse binoculaire comprenant un premier oculaire destiné à recevoir un premier oeil de la personne, un deuxième oculaire destiné à recevoir un deuxième oeil de la personne, un premier capteur d'image adjacent au premier oculaire, et un deuxième capteur d'image adjacent au deuxième oculaire, le dispositif comprenant:

un affichage adjacent à la visionneuse binoculaire; et

un processeur et une mémoire associée coopérant avec ledit affichage et configurés pour

enregistrer, avec le premier capteur d'image, le mouvement du premier oeil,

enregistrer, avec le deuxième capteur d'image, le mouvement du deuxième oeil,

afficher sur ledit affichage un premier stimulus visuel et un deuxième stimulus visuel,

provoquer, de façon alternée, un mouvement convergent et un mouvement divergent dans le premier stimulus visuel et le deuxième stimulus visuel le long d'une trajectoire de stimulus visuel,

déterminer les positions centroïdes respectives du deuxième oeil et du premier oeil pendant le mouvement convergent et divergent du premier stimulus visuel et du deuxième stimulus visuel, et

calculer une distance interpupillaire (IPD), et comparer l'IPD avec la trajectoire de stimulus visuel pour obtenir un IPD dynamique, l'IPD dynamique servant d'indicateur pour savoir si la personne a une CI.

2. Dispositif selon la revendication 1, dans lequel une durée de chacun parmi le mouvement convergent et le mouvement divergent, est de 80 - 100 secondes.

3. Dispositif selon la revendication 1 ou 2, comprenant en outre une première source infrarouge (IR) configurée pour irradier le premier oeil et un deuxième illuminateur infrarouge configuré pour irradier un deuxième oeil; et dans lequel lesdits processeur et mémoire sont configurés pour générer une première pluralité d'images vidéo montrant le mouvement du premier oeil, et générer une deuxième pluralité d'images vidéo montrant le mouvement du deuxième oeil.

4. Dispositif selon la revendication 3, dans lequel ledit processeur et ladite mémoire sont configurés pour:

identifier des deuxièmes pixels de clignotement comprenant des clignotements de deuxième oeil dans la deuxième pluralité d'images vidéo;

former une troisième pluralité d'images vidéo en supprimant les deuxièmes pixels de clignotement de la deuxième pluralité d'images vidéo;

identifier les premiers pixels de clignotement comprenant des clignements de premier oeil dans la première pluralité d'images vidéo; et

former une quatrième pluralité d'images vidéo en supprimant les premiers pixels de clignotement de la première pluralité d'images vidéo.

5. Dispositif selon la revendication 3 ou 4, dans lequel lesdits processeur et mémoire sont configurés pour générer la première pluralité d'images vidéo en effectuant au moins:

filtrer chacune de la première pluralité d'images vidéo en utilisant un seuil d'intensité de pixel pour former une troisième pluralité d'images vidéo, chacune de la troisième pluralité d'images vidéo comprenant un fond noir en combinaison avec un fond blanc, une image de premier oeil, la troisième pluralité d'images vidéo comprenant un nombre N d'images vidéo;

filtrer de chacune de la deuxième pluralité d'images vidéo en utilisant le seuil d'intensité de pixel pour former une quatrième pluralité d'images vidéo, chacune de la quatrième pluralité d'images vidéo comprenant un fond noir en combinaison avec un fond blanc, une image de deuxième oeil, la quatrième pluralité d'images vidéo comprenant un nombre M d'images vidéo;

déterminer, pour chacune des troisièmes images vidéo, les coordonnées x et y d'une première pupille d'oeil centroïde; et

générer une première pluralité d'ensemble de données de coordonnées x;

dans laquelle un $i^{ème}$ ensemble de données de coordonnées x représente un emplacement d'une $i^{ème}$ deuxième pupille centroïde;

dans laquelle i est supérieur ou égal à 1 et inférieur ou égal à N;

déterminer, pour chacune de la quatrième pluralité d'images vidéo, les coordonnées x et y

d'une deuxième pupille d'oeil centroïde; et générer une deuxième pluralité d'ensemble de données de coordonnées x;
dans laquelle un $j^{ième}$ ensemble de données de coordonnées x représente l'emplacement d'une $j^{ième}$ premier centroïde pupillaire;
dans laquelle j est supérieur ou égal à 1 et inférieur ou égal à M.

6. Dispositif selon la revendication 5, dans lequel ledit processeur et ladite mémoire sont configurés pour:

afficher graphiquement une première courbe comprenant N ensemble de données de coordonnées x en fonction du temps; et
afficher graphiquement une deuxième courbe comprenant M ensemble de données de coordonnées x en fonction du temps.

7. Dispositif selon la revendication 6, dans lequel lesdits processeur et mémoire sont configurés pour:

définir i = 1 et j = 1;
soustraire le $i^{ième}$ ensemble de données de coordonnée x du $j^{ième}$ ensemble de données de coordonnée x pour former un $k^{ième}$ ensemble de données de coordonnée x, chacun du $k^{ième}$ ensemble de données de coordonnée x représentant un $h^{ième}$ IPD dynamique;
lorsque i est inférieur à N, définir i = i + 1;
lorsque j est inférieur à M, définir j = j + 1; et
répéter le réglage et la soustraction jusqu'à ce qu'au moins un de i = N et j = M soit vrai.

8. Dispositif selon la revendication 7, dans lequel lesdits processeur et mémoire sont configurés pour former une troisième courbe comprenant chacun des $h^{ième}$ IPD dynamiques en fonction du temps.

9. Dispositif selon la revendication 8, dans lequel lesdits processeur et mémoire sont configurés pour:

identifier une première partie sensiblement linéaire de la troisième courbe, la première partie sensiblement linéaire comprenant une pente positive;
identifier une deuxième partie sensiblement linéaire de la troisième courbe, la deuxième partie sensiblement linéaire comprenant une pente négative;
générer un tracé graphique de la trajectoire de stimulus visuel, le tracé graphique comprenant une première partie linéaire comprenant une pente positive et une deuxième partie linéaire comprenant une pente négative;
superposer la troisième courbe sur le graphique de la trajectoire de stimulus visuel; et
ajuster la troisième courbe pour s'adapter au tracé graphique de la trajectoire de stimulus visuel.

10. Dispositif selon l'une quelconque des revendications précédentes, dans lequel lesdits processeur et mémoire sont configurés pour comparer l'IPD dynamique avec la trajectoire de stimulus visuel en effectuant au moins:

optimiser un graphique d'IPDs dynamiques avec au moins un paramètre; et
fusionner le graphe optimisé d'IPDs dynamiques avec la trajectoire de stimulus visuel.

11. Support non transitoire lisible par ordinateur ayant des instructions exécutables par ordinateur pour amener un dispositif informatique comprenant un processeur et une mémoire associée à exécuter un procédé pour dépister une insuffisance de convergence (CI) d'une personne, le procédé comprenant:

enregistrer, avec un premier capteur d'image, le mouvement d'un premier oeil de la personne;
enregistrer, avec un deuxième capteur d'image, le mouvement d'un deuxième oeil de la personne;
afficher sur un affichage un premier stimulus visuel et un deuxième stimulus visuel;
provoquer, d'une façon alternative, un mouvement convergent et un mouvement divergent dans le premier stimulus visuel et le deuxième stimulus visuel le long d'une trajectoire de stimulus visuel;
déterminer les positions centroïdes respectives du deuxième oeil et du premier oeil pendant le mouvement convergent et divergent du premier stimulus visuel et du deuxième stimulus visuel; et
calculer une distance interpupillaire (IPD) et comparer l'IPD avec la trajectoire de stimulus visuel pour obtenir un IPD dynamique, l'IPD dynamique servant d'indicateur permettant de savoir si la personne a une CI.

12. Support non transitoire lisible par ordinateur selon la revendication 11, dans lequel une durée de chacun du mouvement convergent et du mouvement divergent est de 80 - 100 secondes.

13. Support non transitoire lisible par ordinateur selon la revendication 11 ou 12, dans lequel le procédé comprend:

utiliser une première source infrarouge (IR) configurée pour irradier le premier oeil et un deuxième illuminateur IR configuré pour irradier un deuxième oeil; et
générer une première pluralité d'images vidéo montrant le mouvement du premier oeil et gé-

nérer une deuxième pluralité d'images vidéo montrant un mouvement du deuxième oeil.

14. Support lisible par ordinateur non transitoire selon la revendication 13, dans lequel le procédé comprend:

identifier des deuxièmes pixels de clignotement comprenant des clignements de deuxième oeil dans la deuxième pluralité d'images vidéo;
former une troisième pluralité d'images vidéo en supprimant les deuxièmes pixels de clignotement de la deuxième pluralité d'images vidéo;
identifier des premiers pixels de clignotement comprenant des clignements de premier oeil dans la première pluralité d'images vidéo; et
former une quatrième pluralité d'images vidéo en supprimant les premiers pixels de clignotement de la première pluralité d'images vidéo.

15. Support non transitoire lisible par ordinateur selon la revendication 13 ou 14, dans lequel la génération de la première pluralité d'images vidéo comprend:

filtrer chacune de la première pluralité d'images vidéo en utilisant un seuil d'intensité de pixel pour former une troisième pluralité d'images vidéo, chacune de la troisième pluralité d'images vidéo comprenant un fond noir en combinaison avec un fond blanc, une image de premier oeil, la troisième pluralité d'images vidéo comprenant un nombre N d'images vidéo;
filtrer de chacune de la deuxième pluralité d'images vidéo en utilisant le seuil d'intensité de pixel pour former une quatrième pluralité d'images vidéo, chacune de la quatrième pluralité d'images vidéo comprenant un fond noir en combinaison avec un fond blanc, une image de deuxième oeil, la quatrième pluralité d'images vidéo comprenant un nombre M d'images vidéo;
déterminer, pour chacune de la troisième pluralité d'images vidéo, les coordonnées x et y d'une première pupille d'oeil centroïde; et
générer une première pluralité d'ensemble de données de coordonnées x;
dans lequel un ensemble de données de coordonnées x représente un emplacement d'une $i^{ème}$ deuxième pupille centroïde;
dans lequel i est supérieur ou égal à 1 et inférieur ou égal à N;
déterminer, pour chacune de la quatrième pluralité d'images vidéo, les coordonnées x et y d'une deuxième pupille d'oeil centroïde; et
générer une deuxième pluralité d'ensemble de données de coordonnées x;
dans lequel un ensemble de données de coordonnées x représente l'emplacement d'un $j^{ème}$ premier centroïde pupillaire;
dans lequel j est supérieur ou égal à 1 et inférieur ou égal à M.

FIG. 1

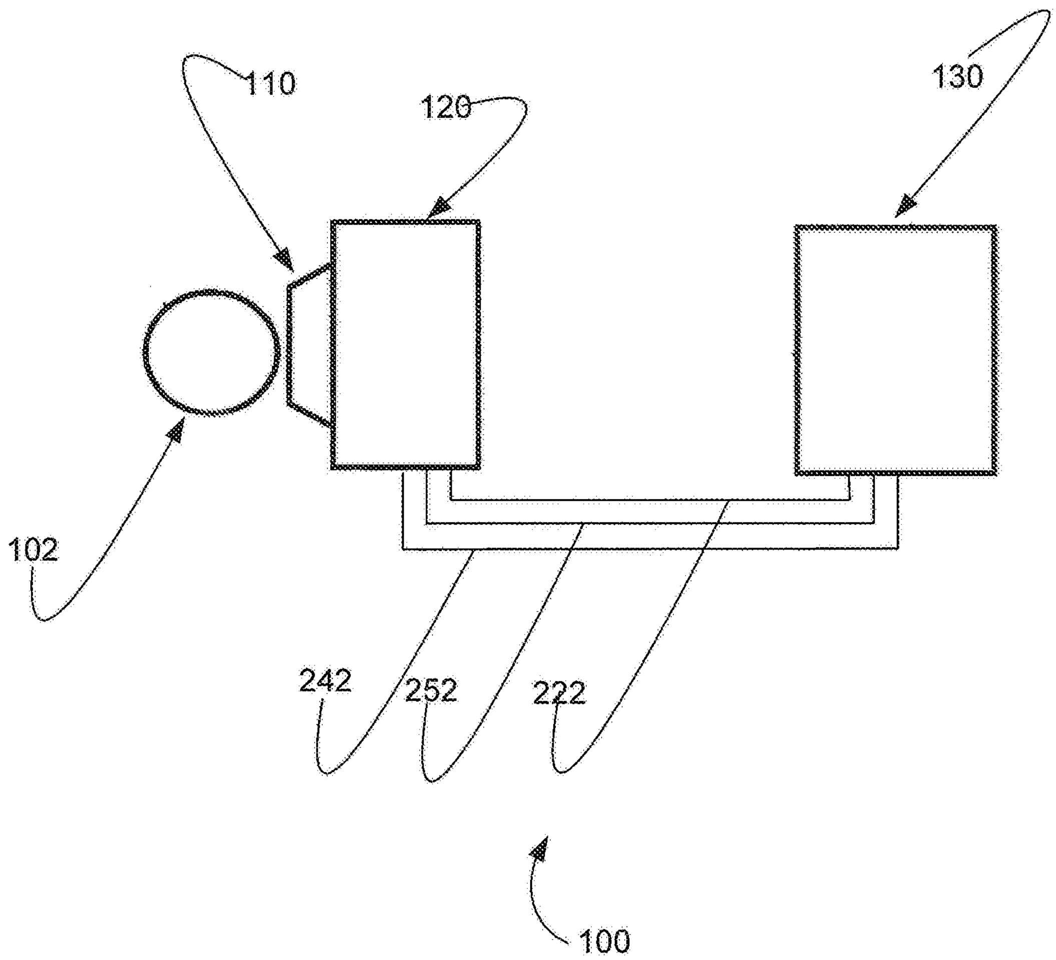
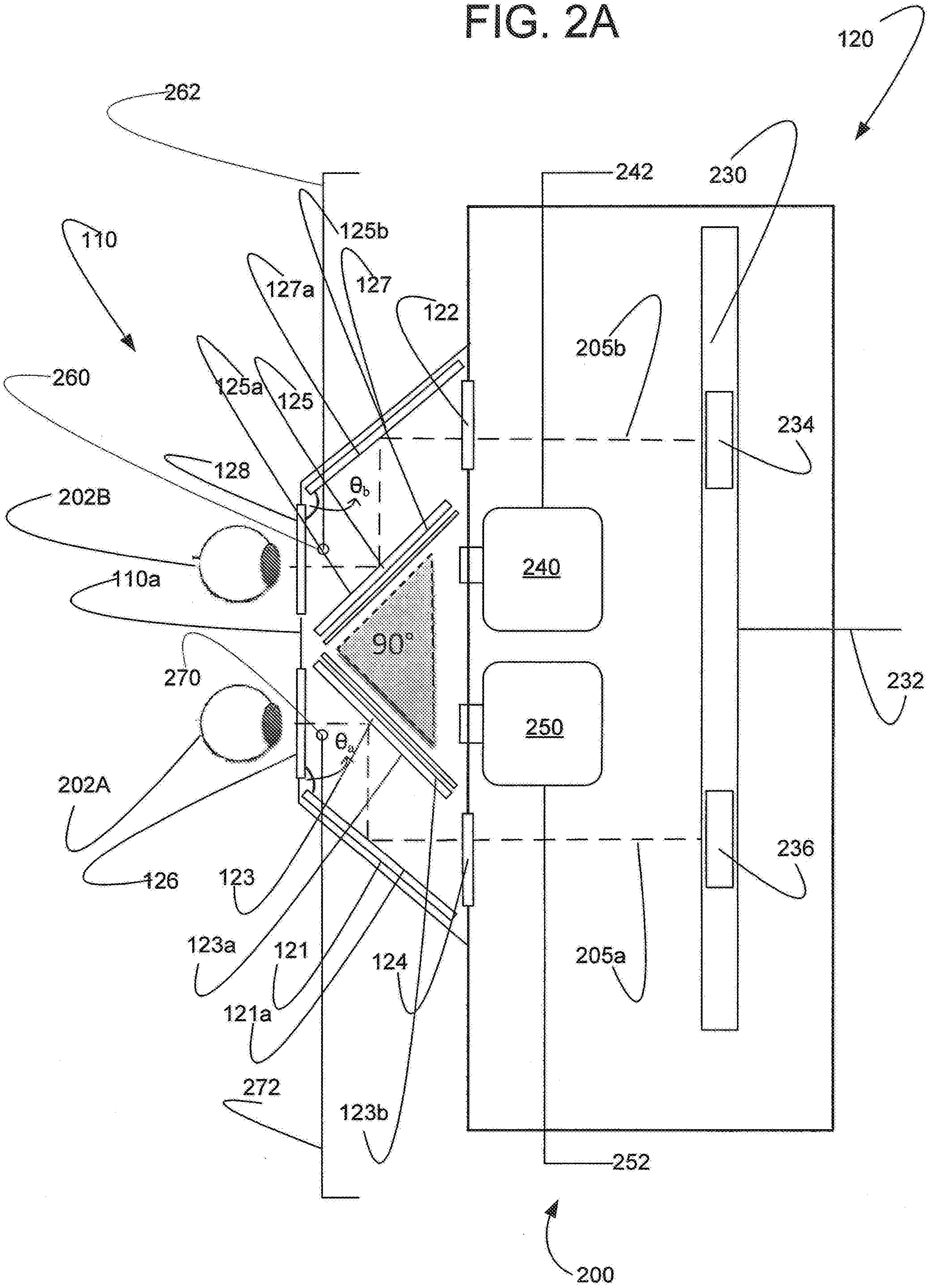
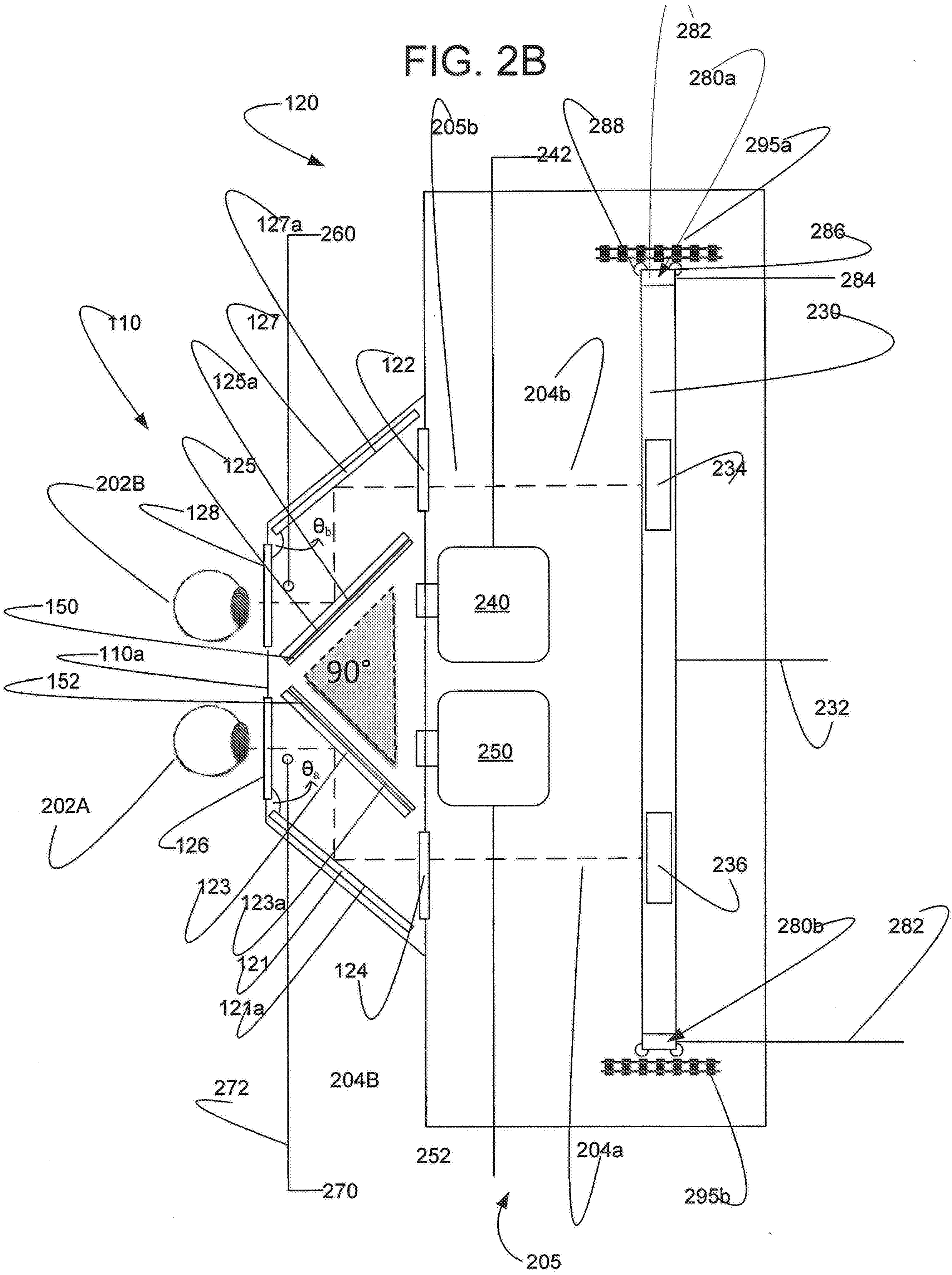


FIG. 2A



120
262
242
230
110
125b
127a
127
122
205b
260
125a
125
234
128
θb
202B
240
110a
90°
232
270
250
θa
202A
236
126
123
123a
121
124
205a
121a
272
123b
252
200

FIG. 2B


282
280a
120
205b
288
295a
242
127a
260
286
284
110
127
230
122
125a
204b
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234
202B
128
θb
240
150
110a
90°
152
250
232
θa
202A
126
236
123
123a
280b
282
121
124
121a
272
204B
252
204a
270
295b
205

FIG. 3A

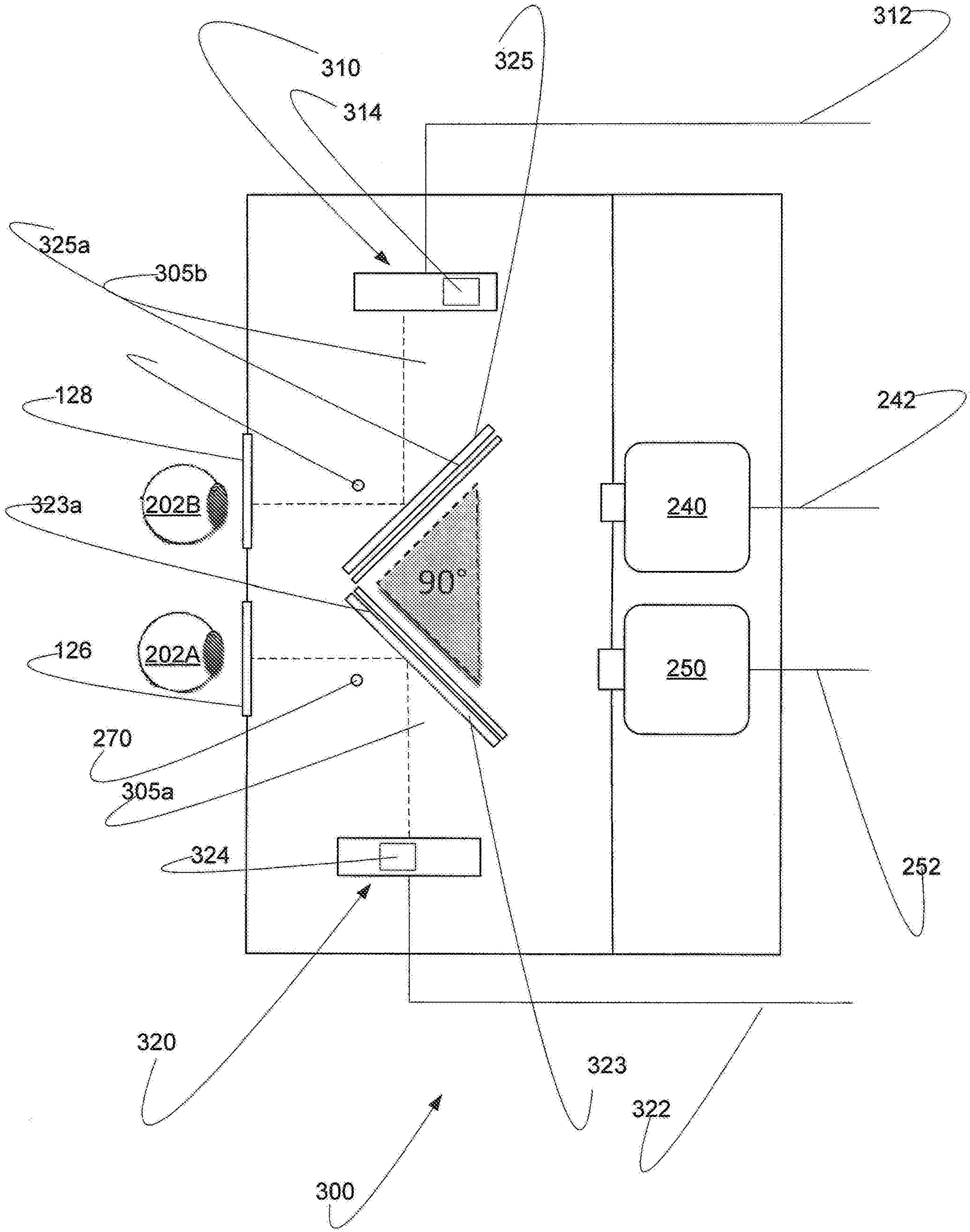

312
310
325
314
325a
305b
128
242
323a
202B
240
90°
126
202A
250
270
305a
324
252
320
323
322
300

FIG. 3B

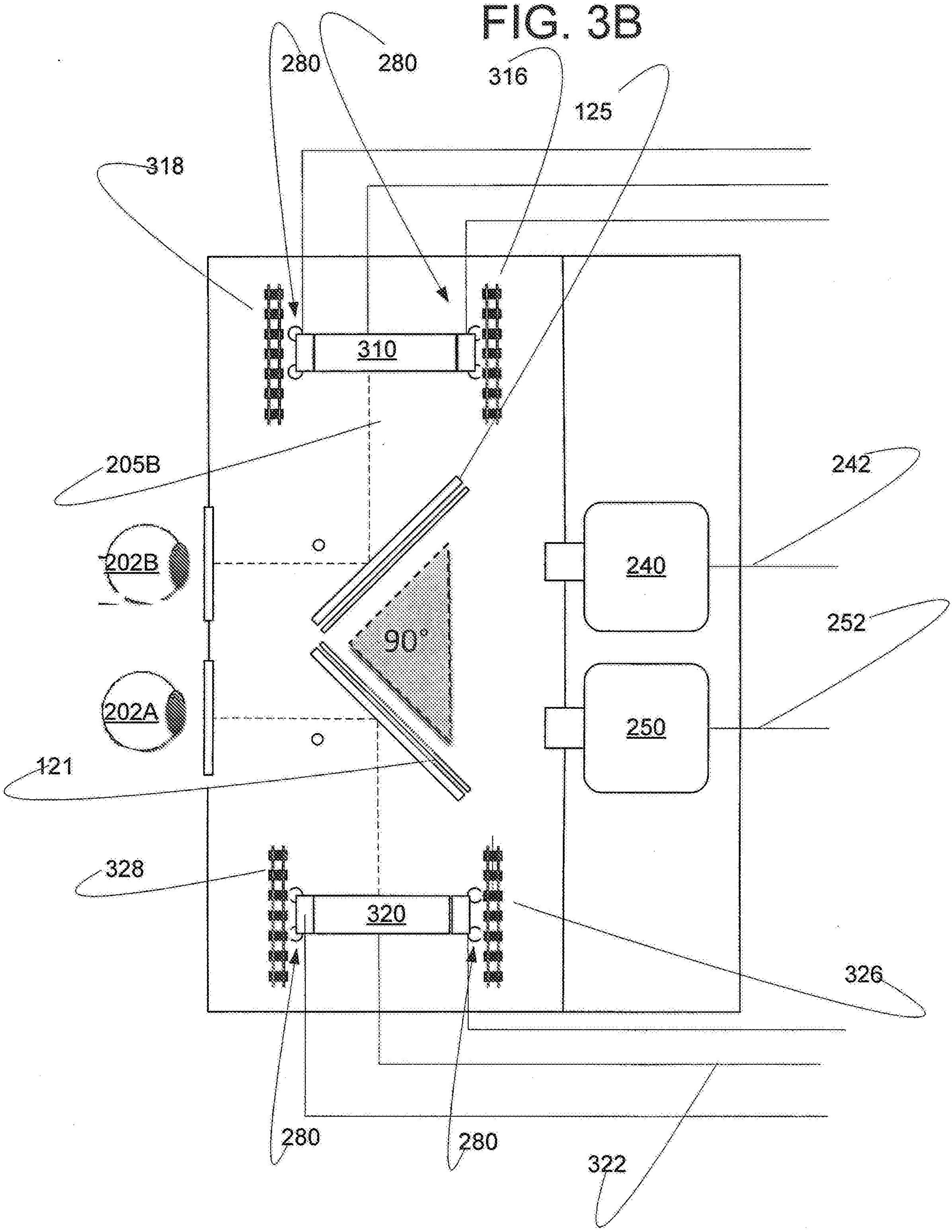

280
280
316
125
318
310
205B
242
202B
240
90°
252
202A
250
121
328
320
326
280
280
322

FIG. 4

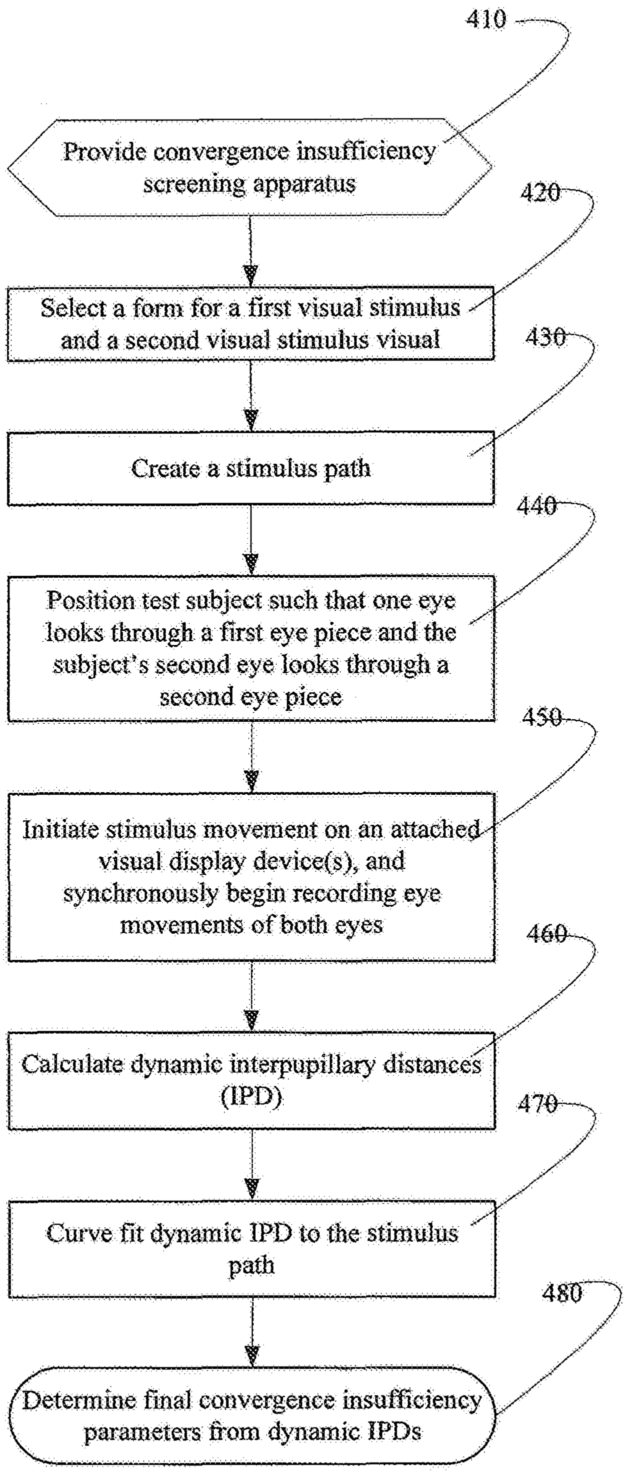
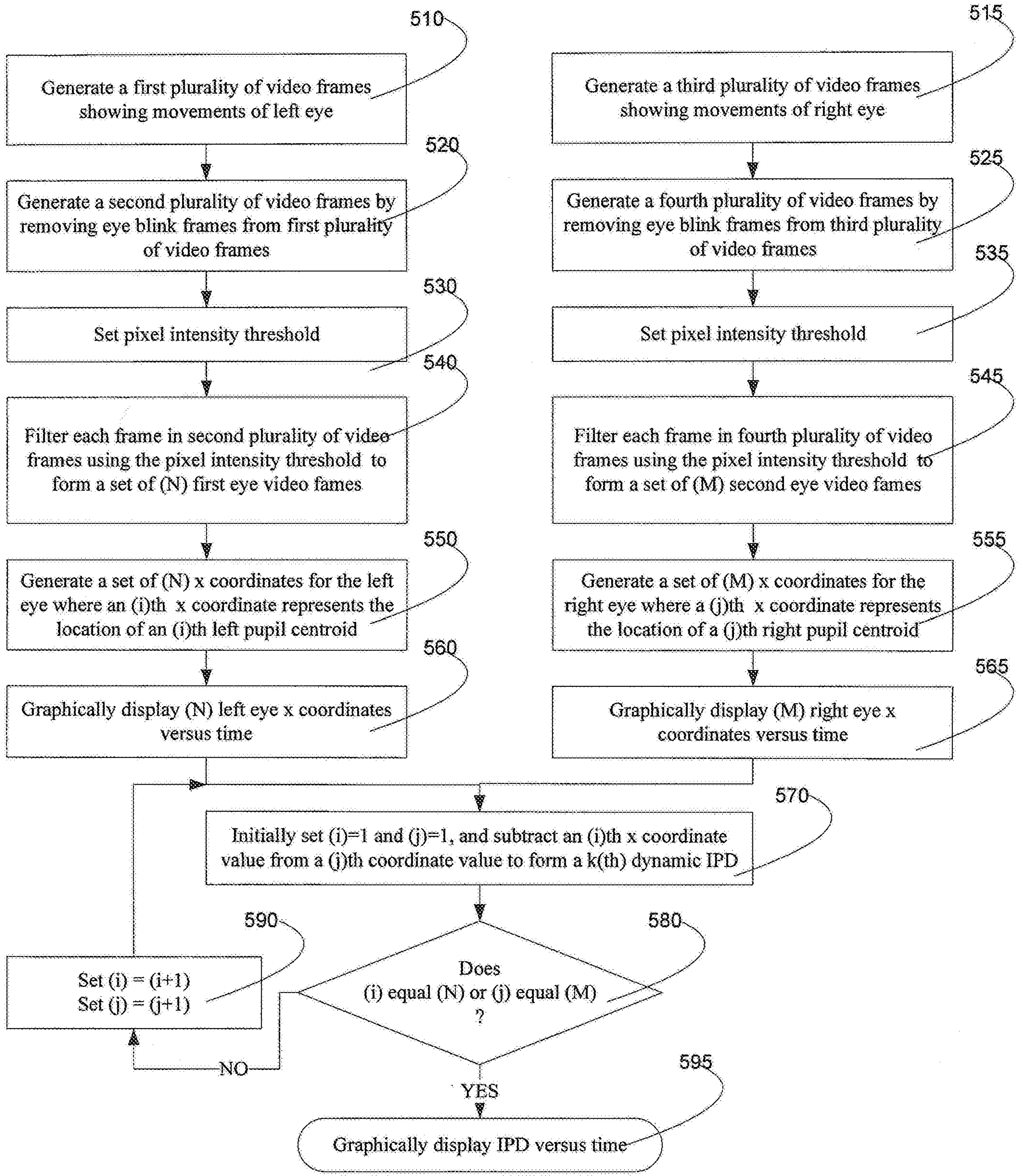

410
Provide convergence insufficiency screening apparatus
420
Select a form for a first visual stimulus and a second visual stimulus visual
430
Create a stimulus path
440
Position test subject such that one eye looks through a first eye piece and the subject's second eye looks through a second eye piece
450
Initiate stimulus movement on an attached visual display device(s), and synchronously begin recording eye movements of both eyes
460
Calculate dynamic interpupillary distances (IPD)
470
Curve fit dynamic IPD to the stimulus path
480
Determine final convergence insufficiency parameters from dynamic IPDs

FIG. 5


510
Generate a first plurality of video frames showing movements of left eye
515
Generate a third plurality of video frames showing movements of right eye
520
Generate a second plurality of video frames by removing eye blink frames from first plurality of video frames
525
Generate a fourth plurality of video frames by removing eye blink frames from third plurality of video frames
530
Set pixel intensity threshold
535
Set pixel intensity threshold
540
Filter each frame in second plurality of video frames using the pixel intensity threshold to form a set of (N) first eye video fames
545
Filter each frame in fourth plurality of video frames using the pixel intensity threshold to form a set of (M) second eye video fames
550
Generate a set of (N) x coordinates for the left eye where an (i)th x coordinate represents the location of an (i)th left pupil centroid
555
Generate a set of (M) x coordinates for the right eye where a (j)th x coordinate represents the location of a (j)th right pupil centroid
560
Graphically display (N) left eye x coordinates versus time
565
Graphically display (M) right eye x coordinates versus time
570
Initially set (i)=1 and (j)=1, and subtract an (i)th x coordinate value from a (j)th coordinate value to form a k(th) dynamic IPD
590
Set (i) = (i+1)
Set (j) = (j+1)
580
Does (i) equal (N) or (j) equal (M) ?
NO
YES
595
Graphically display IPD versus time

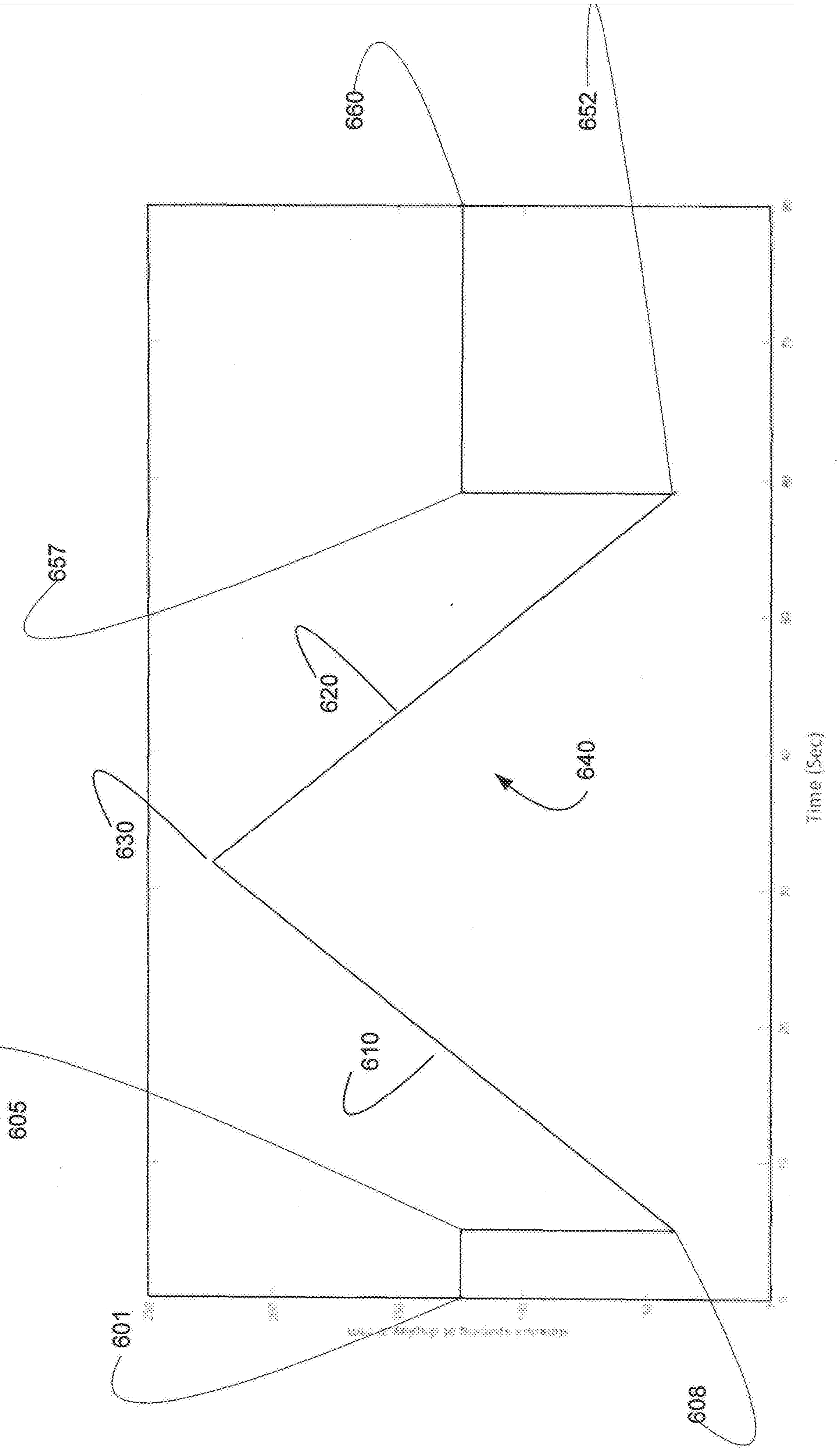
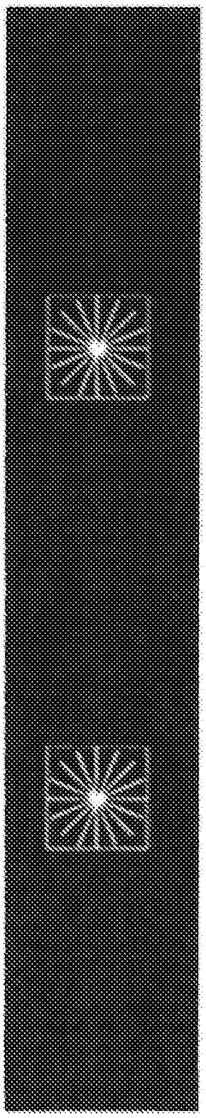


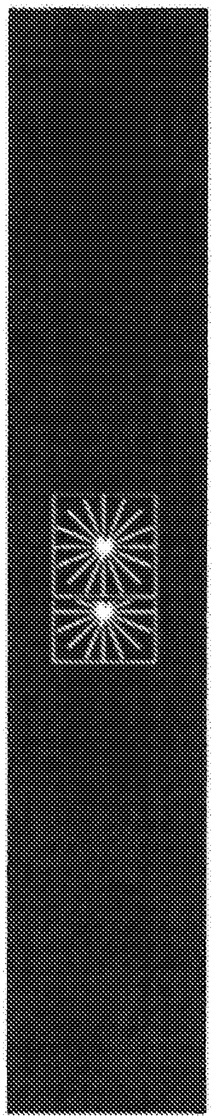
FIG. 6A

FIG. 6B



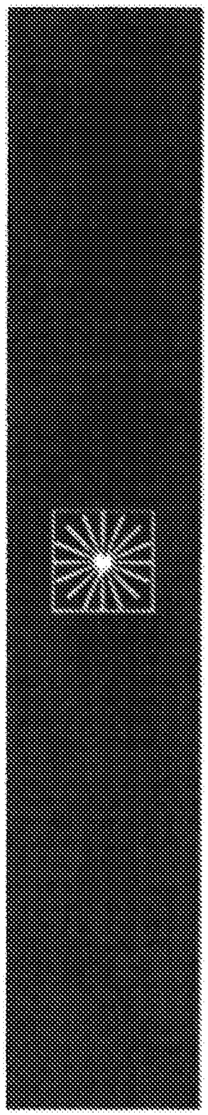
Stimuli unmerged to subject's eyes

FIG. 6C



Stimuli merging to subject's eyes

FIG. 6D



Stimuli merged to subject's eyes

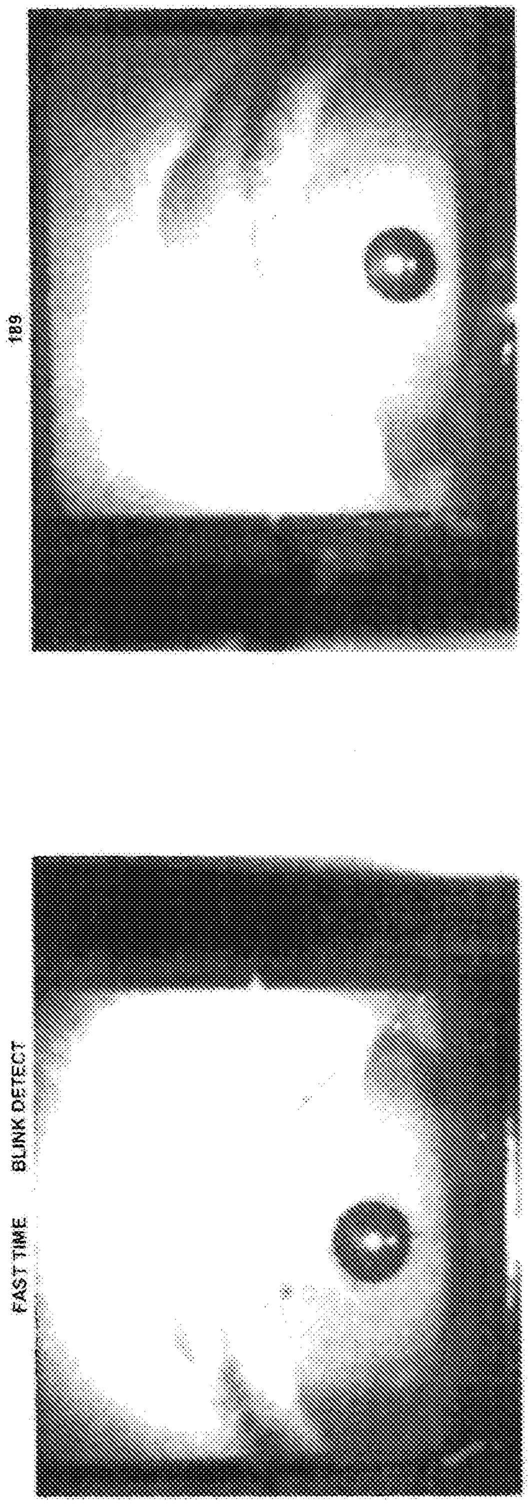


FIG. 7

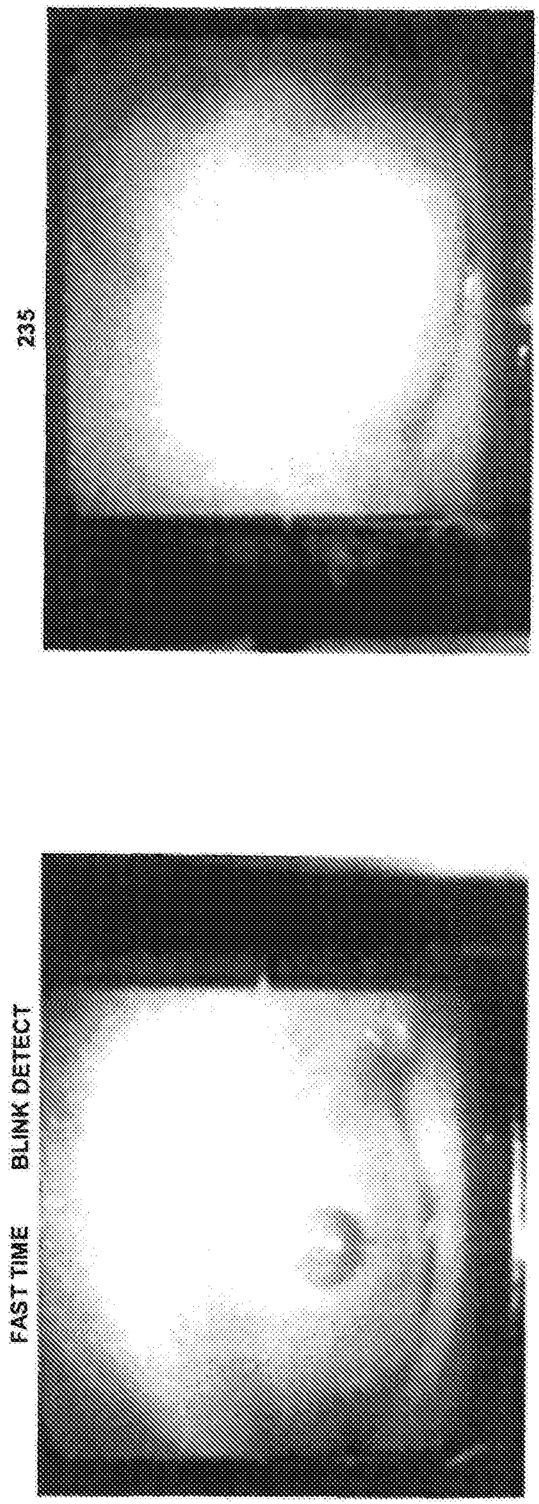


FIG. 8

FIG. 9A

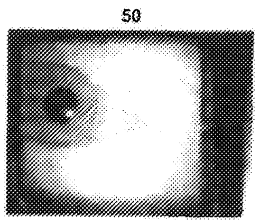
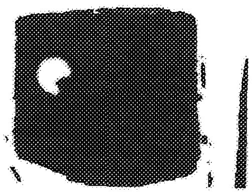
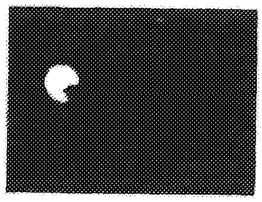


FIG. 9B



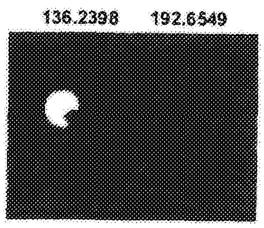
THRESHOLDED
EYE IMAGE

FIG. 9C



CLEARED BORDER
DELETED SMALL
BLOBS

FIG. 9D



ONE BLOB
REMAINING

FIG. 10

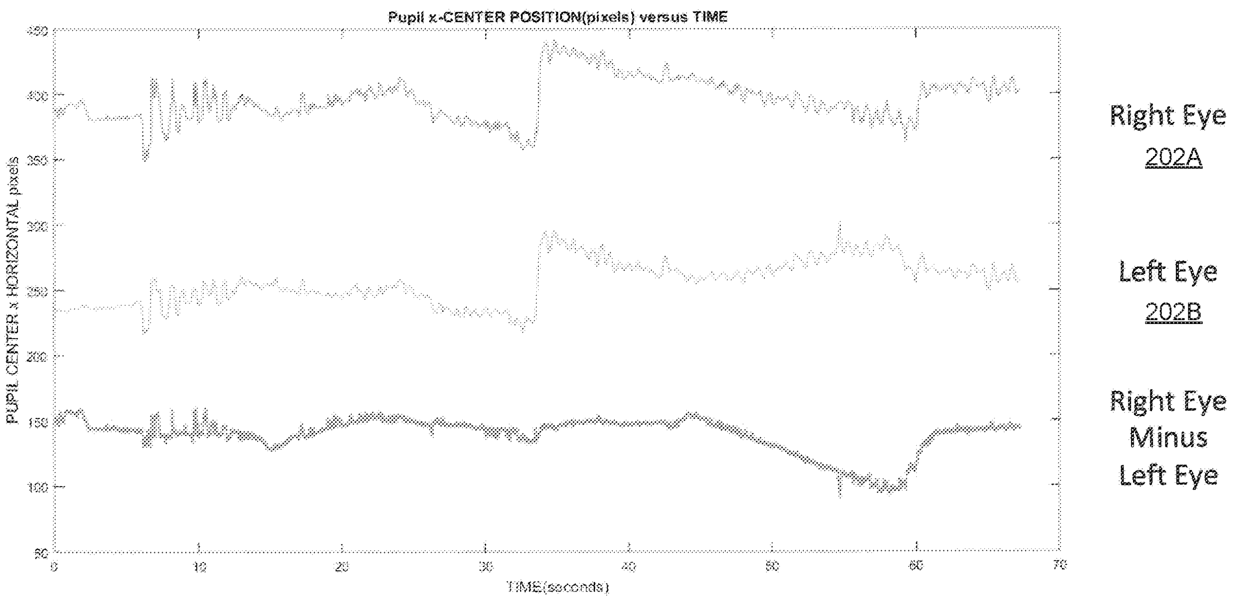

Pupil x-CENTER POSITION(pixels) versus TIME
PUPIL CENTER x HORIZONTAL pixels
TIME(seconds)
Right Eye
202A
Left Eye
202B
Right Eye
Minus
Left Eye

FIG. 11

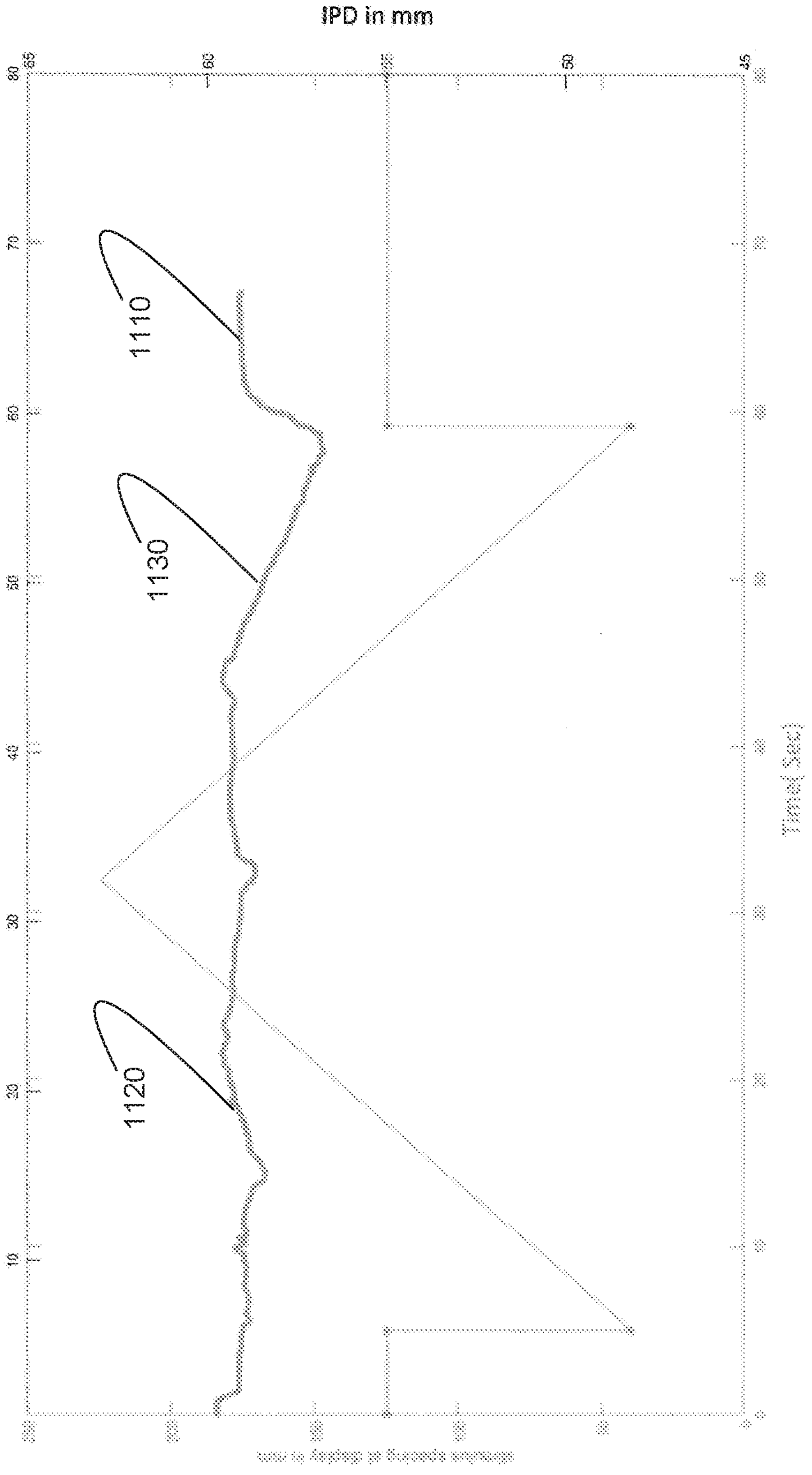

IPD in mm
65
60
55
50
45
10
20
30
40
50
60
70
80
1110
1130
1120
Time(Sec)

FIG. 12

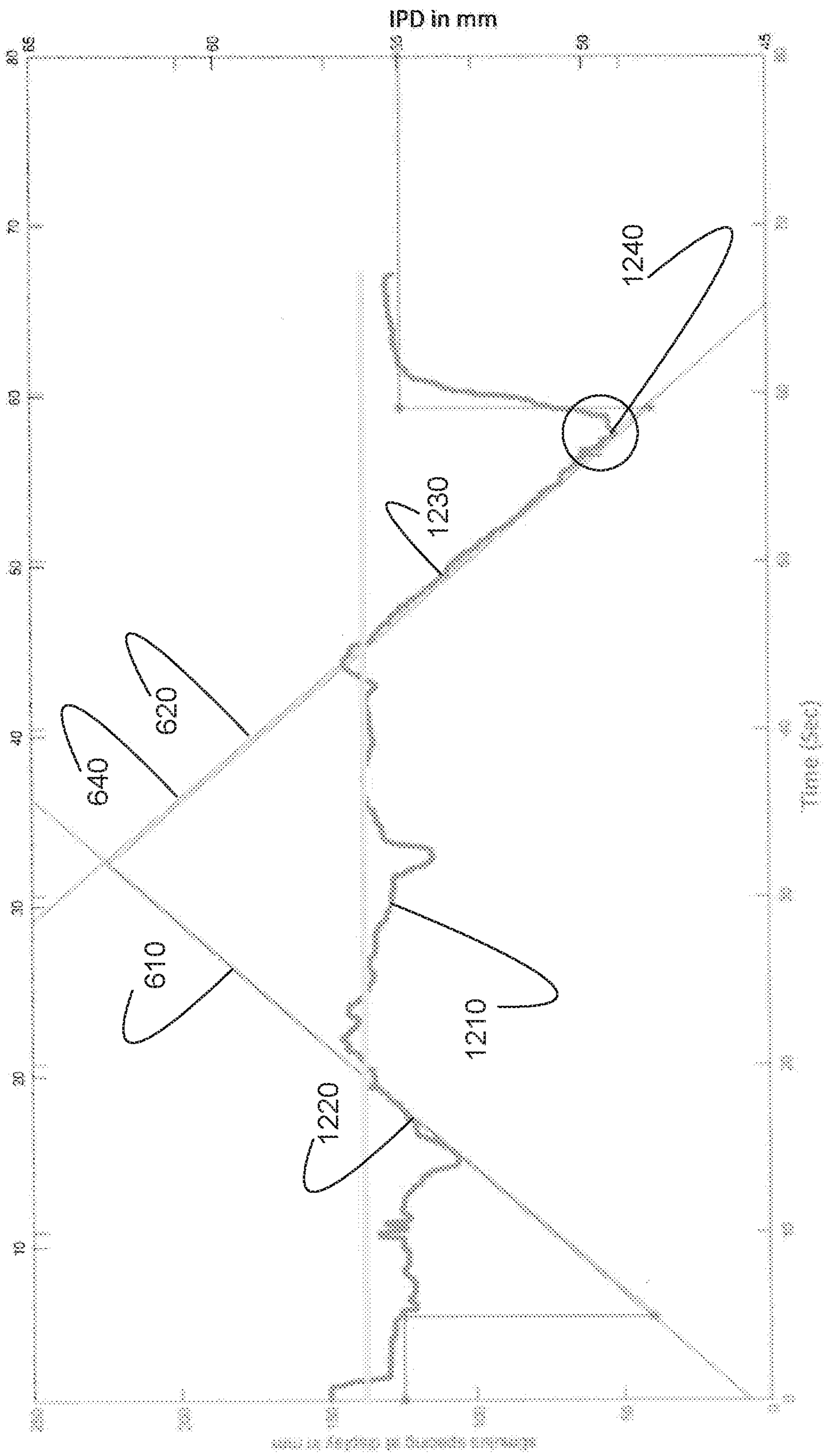


FIG. 13A

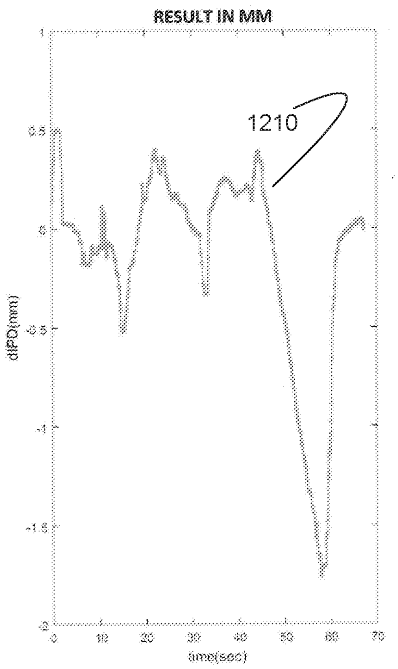


FIG. 13B

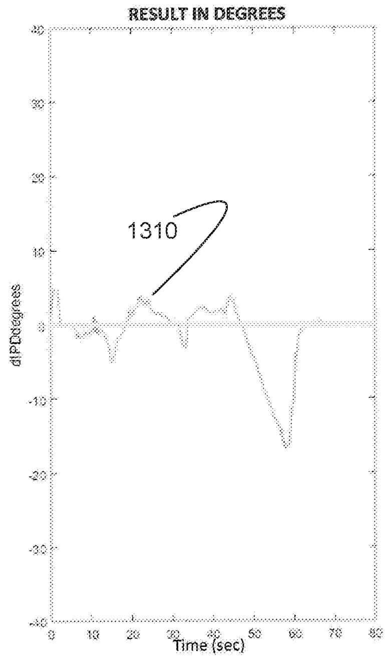


FIG. 13C

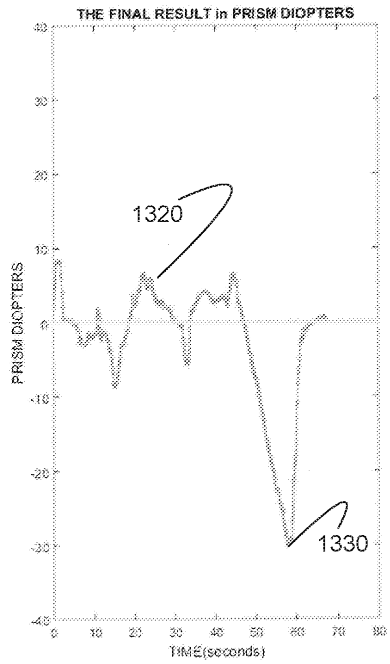


FIG. 14

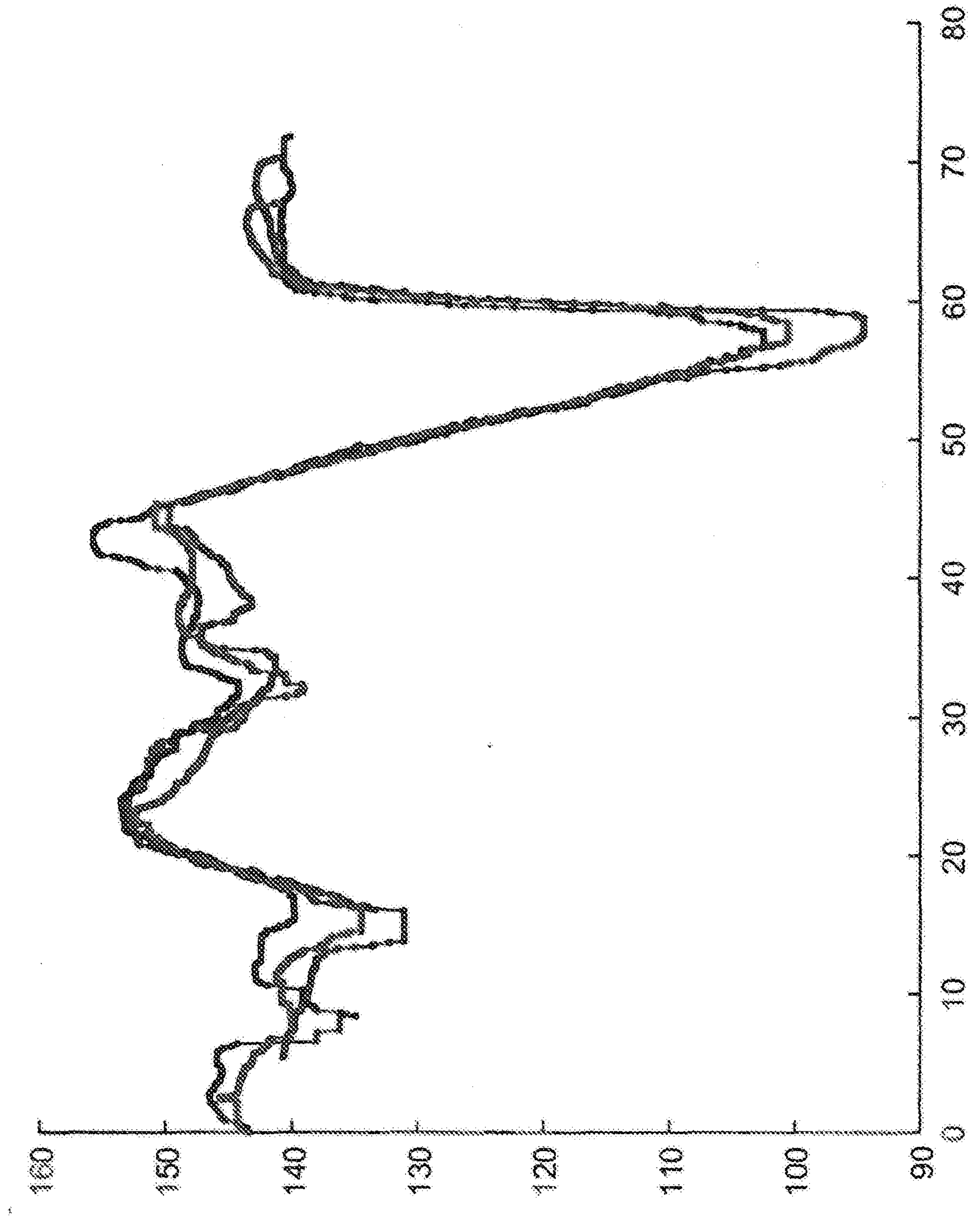


FIG. 15

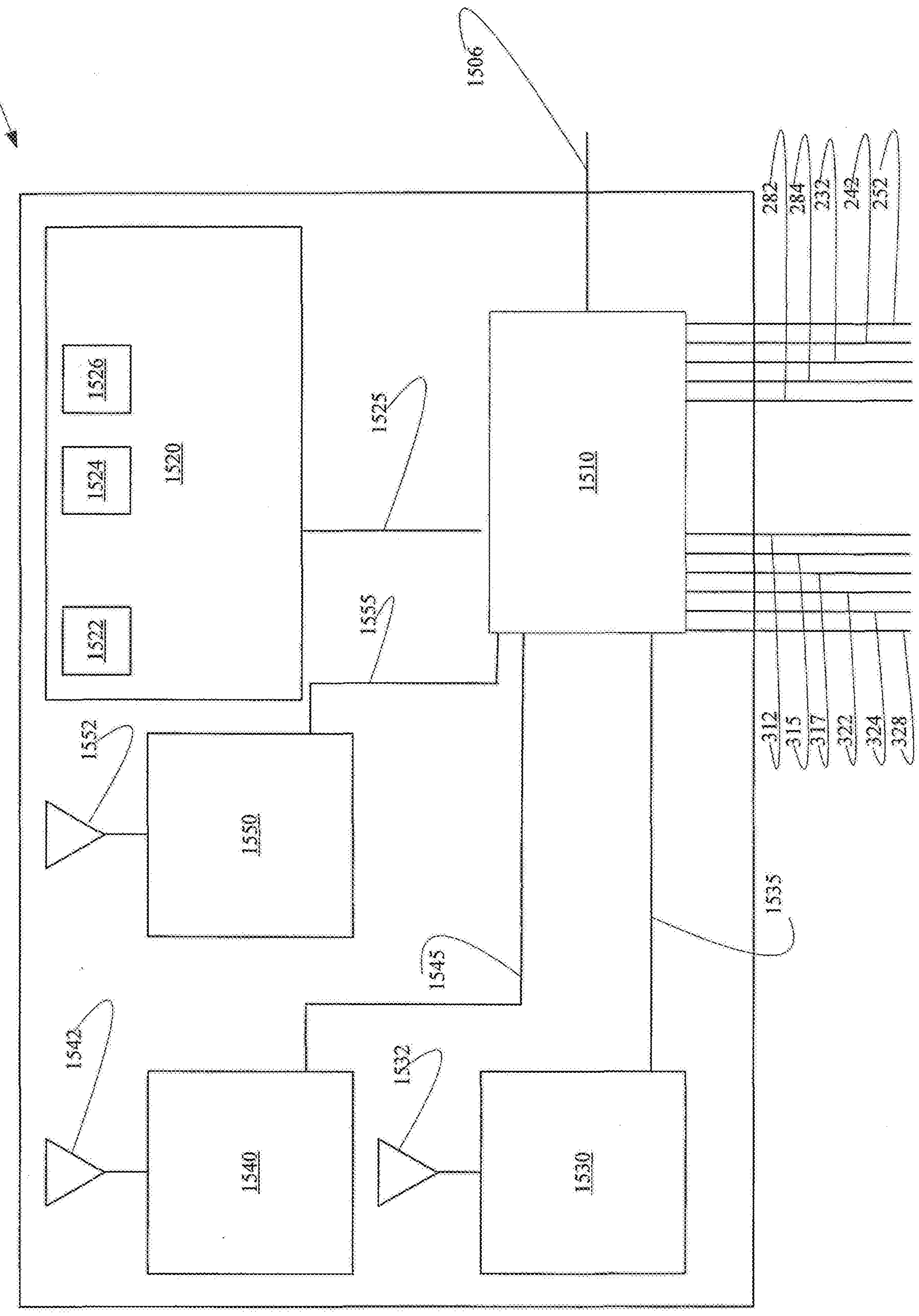

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FIG. 16A

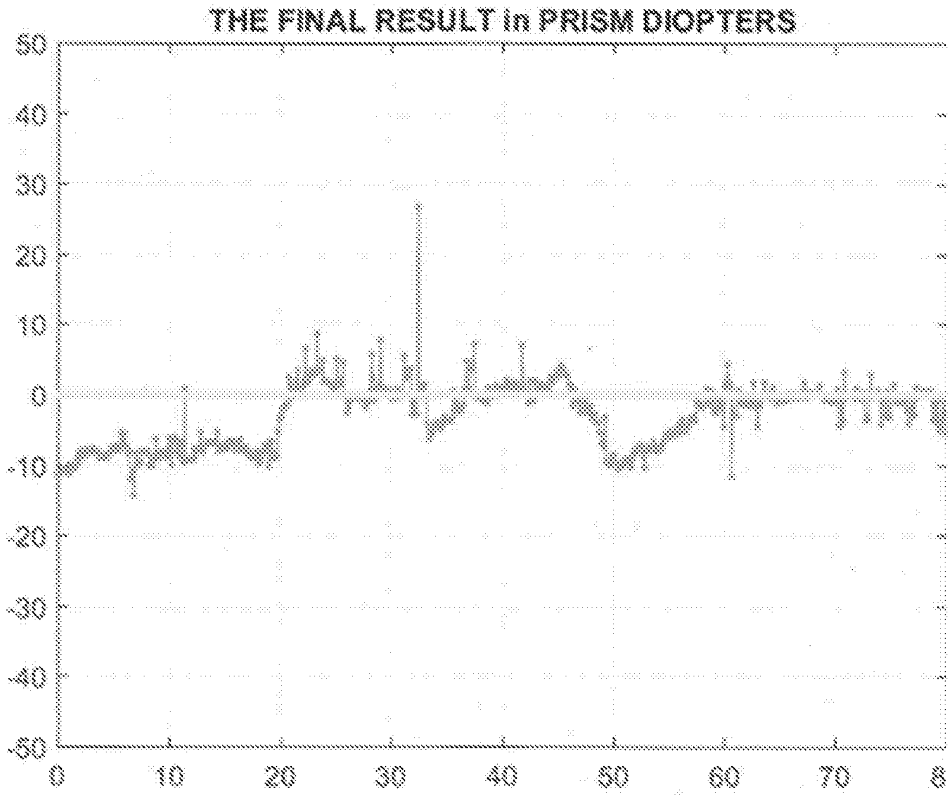
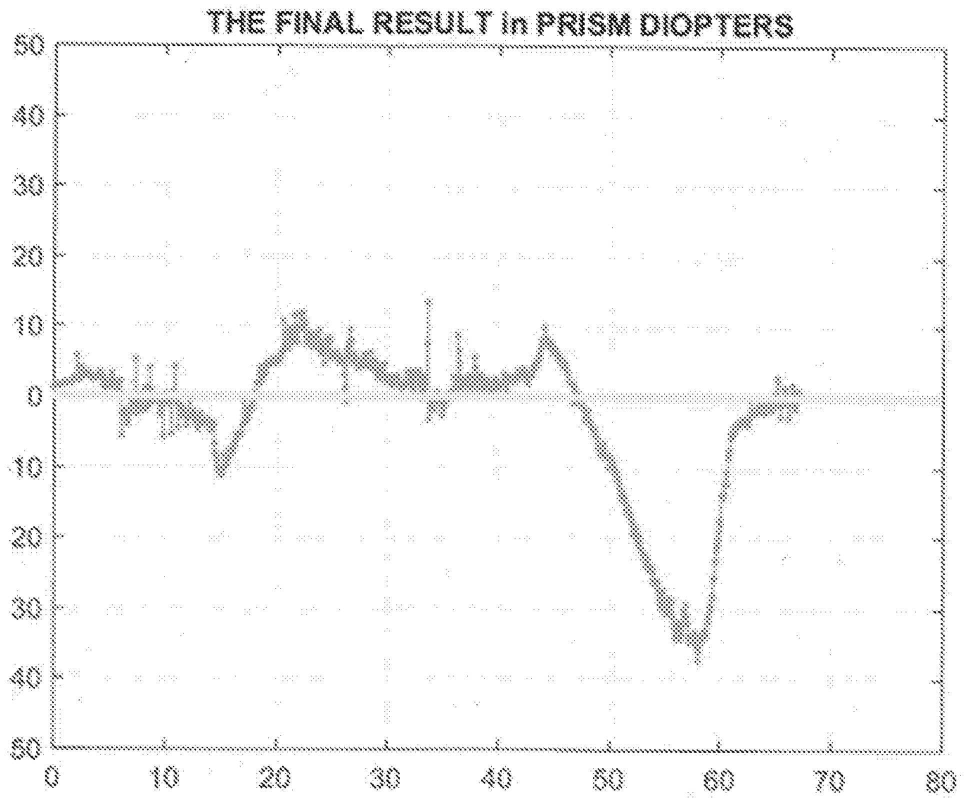


FIG. 16B



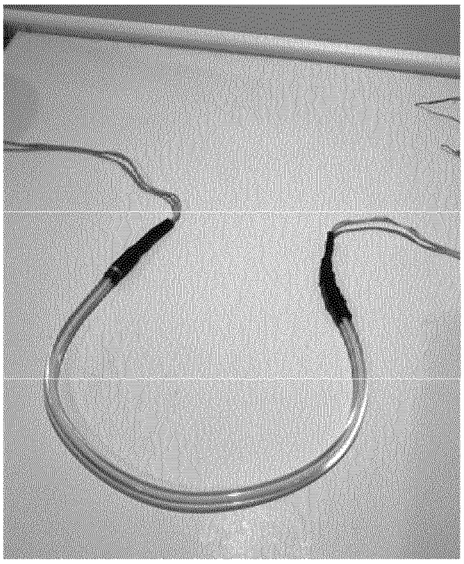


FIG. 17

FIG. 18

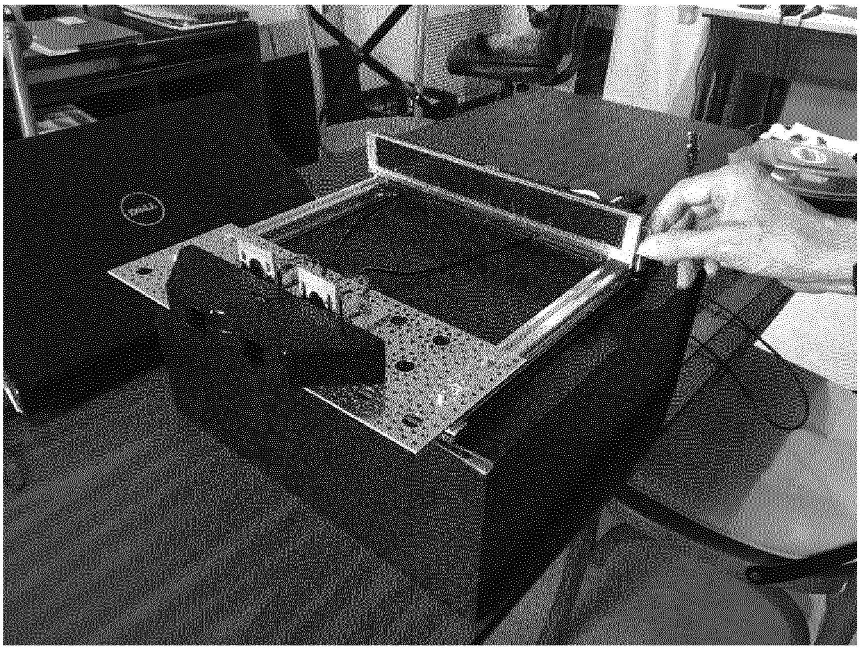


FIG. 19

REFERENCES CITED IN THE DESCRIPTION

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- EP 2891953 A **[0004]**
- WO 2008120635 A **[0004]**
- JP 2002017677 B **[0004]**